ISSN 0727-0097

ADVANCES IN THE STUDY OF THE SYDNEY BASIN

PROCEEDINGS OF THE TWENTY FOURTH SYMPOSIUM

23rd to 25th MARCH, 1990

DEPARTMENT OF GEOLOGY
THE UNIVERSITY OF NEWCASTLE N.S.W. 2308

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TWENTY FOURTH NEWCASTLE SYMPOSIUM

ON

"ADVANCES IN THE STUDY OF THE SYDNEY BASIN"

23rd to 25th MARCH, 1990

NEWCASTLE N.S.W. AUSTRALIA

I.R.PLIMER
CONVENER

THE UNIVERSITY OF NEWCASTLE

New South Wales 2308

DEPARTMENT OF GEOLOGY

Publication No. 344

FOREWORD

Welcome to the 24th Newcastle Symposium on "Advances in the Study of the Sydney Basin". The Symposium this year has its theme on a very unusual geological event: the Newcastle Earthquake of 28th December, 1989. Although the seismic aspects of the Sydney Basin have often been described in previous Symposia, the Newcastle Earthquake is of special significance because it was the first fatal Australian earthquake. Such a geological phenomenon provide us with a great opportunity to educate the community about basic earth science. All the geology staff have been active in this public service role as a mechanism of increasing community geological awareness.

The Department of Geology again faces a very difficult year with increasing student numbers (especially at the senior level) and staff levels which are below the critical mass. To some extent, the Department is a victim of its own success and, although the situation will be partially alleviated by the appointment of one untenured lecturer in 1990, the labour-intensive senior teaching is putting a great strain on the Department's resources. Nevertheless, staff of the Department continue to win competitive research grants from ARC and NERDDC.

This Symposium exists partially because of the Department's reputation for coal geology. The contributions to coal geology by Claus Diessel have been recognised by the University who appointed him to a Personal Chair in December, 1989. I'm sure conference participants join me in congratulating Professor Diessel on this achievement - a fitting recognition for his contributions.

I.R. PLIMER
Convenor, Head of Department

PROGRAM

24th Newcastle Symposium
"ADVANCES IN THE STUDY OF THE SYDNEY BASIN"

THURSDAY **22nd March 1990**

10:00 MEETING of the Working Group MN1/1/1 (Petrography) of the Standards Association of Australia

FRIDAY **23rd March, 1990**

13:30 - 17:30 EXCURSION

"THE NEWCASTLE EARTHQUAKE – WHOSE FAULTS?"

Leaders : D.F. Branagan, G. Dean-Jones & K.H.R. Moelle

Departure point : Coach will leave from the University No. 1 Car Park (near the Great Hall) at 13:30

The excursion will inspect some of the affected areas with the view of relating the severity of damage to the geological environment.

Included is participation in the Graduates' Society Sheep Roast

18:30 - 23:00 UNIVERSITY OF NEWCASTLE GRADUATES' SOCIETY SHEEP ROAST

SATURDAY 24th March, 1990

08:30 - 09:00 **REGISTRATION - Geology Department Foyer**

LECTURE THEATRE B01

09:00 - 09:05 **Welcome by the Head of the Geology Department, Professor Ian Plimer**

09:05 - 09:10 **OPENING of the 24th NEWCASTLE SYMPOSIUM by the Vice Chancellor of the University of Newcastle, Professor Keith Morgan**

TECHNICAL SESSION 1

LECTURE THEATRE E01

CHAIR : Dr D.F. Branagan

09:15 - 09:45

Structural elements of the Hunter Coalfield : a preliminary assessment

T.P.T. McLennan & E.M. Lohe
CSIRO Div. Geomechanics

09:45 - 10:15

A reinterpretation of Permian Tectonism in the Sydney Basin and Southern New England Fold Belt :

W.J. Collins
University of Newcastle

CHAIR : SUMMARY and VOTE OF THANKS

TECHNICAL SESSION 2

LECTURE THEATRE B01

CHAIR : M.B.L. Hill

09.15 - 09.45

Geophysical logs and correlation in the southern Sydney Basin

A. Hutton
University of Wollongong

09:45 - 10.15

Application of high resolution seismic predictions to mining - a case history

J. Hanes & P. Maddocks
BHP Collieries Divn., Wollongong

CHAIR : SUMMARY and VOTE OF THANKS

10:15 - 10:45 MORNING TEA IN THE FOYER OF THE GREAT HALL

SATURDAY 24th March, 1990

TECHNICAL SESSION 3

LECTURE THEATRE E01

CHAIR : Rod Davis

10:45 - 11:15

Marine influence on coal seams :

C.F.K. Diessel
University of Newcastle

11:15 - 11:45

German Creek Formation and Moranbah Coal Measures : a transition from marine shelf to upper delta plain :

A. Falkner & C.R. Fielding
University of Queensland

11:45 - 12:15

Aspects of the Lower Permian sequences in the Manning River area and their tectonic significance :

R. Jenkins
University of Newcastle

12:15 - 12:45

Progress in three-dimensional seismic surveying, Appin area :

P. Hatherly[1] & G. Poole[2]
[1] ACIRL, North Ryde
[2] BHP T & ES, Figtree

CHAIR : SUMMARY and VOTE OF THANKS

TECHNICAL SESSION 4

LECTURE THEATRE B01

CHAIR : Ian Plimer

10:45 - 11:15

The application of bore core seam desorption data to mine planning in multi-seam environments :

G. May & A.B. Paul
McElroy Bryan Geological Services

11:15 - 11:45

Coal seam methane. Problems of determination, administration and utilisation :

M.B.L. Hill & M. Armstrong
Geological Survey of NSW

11:45 - 12:15

'RAMBOE' – A thermal maturity technique for oil exploration based on the raman and fluorescence properties of coal macerals :

R.W.T. Wilkins, J.R. Wilmshurst, G. Hladky, M.E. Ellacott & C. Buckingham
CSIRO Div. Exploration Geoscience

12:15 -12:45

Isotopic and fluid inclusion studies of fluid flow history in the Narrabeen Sandstone :

G.P. Bai[1], P.J. Hamilton[2], P.J. Eadington[2] & J.B. Keene[1]
[1] University of Sydney
[2] CSIRO Division of Exploration Geoscience

CHAIR : SUMMARY and VOTE OF THANKS

12:45 - 02:00 LUNCH in the University Union

TECHNICAL SESSION 5

LECTURE THEATRE E01

CHAIR : Scott Thompson

14:00 - 14:30

The application of cross hole seismic (CHS) and in-seam seismic (ISS) in the detection of old coal mine workings :

J.F. Doyle, A.R. Newland & R. Gritto
BHP Engineering, Wollongong

14:30 - 15:00

Geophysical detection of old mine workings :

P. Hatherly[1] & G. Won[2]
[1] ACIRL, North Ryde
[2] RTA, Sydney

CHAIR : SUMMARY and VOTE OF THANKS

TECHNICAL SESSION 6

LECTURE THEATRE B01

CHAIR : Ted Brennan

14:00 - 14:30

Some geotechnical phenomena related to high stresses in the Hawkesbury Sandstone :

J. Braybrooke
D.J. Douglas & Partners

14:30 - 15:00

Some newly exposed faults in the Sydney region :

D.F. Branagan & K.J. Mills
University of Sydney

CHAIR : SUMMARY and VOTE OF THANKS

15:00 - 15:25 **AFTERNOON TEA in the foyer of the GREAT HALL**

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TECHNICAL SESSION 7

THE GREAT HALL, UNIVERSITY OF NEWCASTLE

PUBLIC SESSION ON "THE NEWCASTLE EARTHQUAKE"

CHAIR : Ald. John McNaughton, Lord Mayor of Newcastle

15:30 - 16:10

******* KEYNOTE ADDRESS *******
THE 1989 NEWCASTLE EARTHQUAKE
AND THE SEISMICITY OF THE SYDNEY BASIN
D. DENHAM & K. McCUE, Bureau of Mineral Resources

16:10 - 16:30
The Newcastle Earthquake – The Taskforce
Sgt. J. HOPGOOD, Queensland Police Operations Branch

16:30 - 16:50
Engineering Geological Considerations subsequent to the Newcastle Earthquake
G. DEAN-JONES, D. BRANAGAN & K.H.R. MOELLE, Newcastle University

16:50 - 17:10
Earthquake Risk in Eastern Australia - Lessons from Newcastle
J. RYNN, University of Queensland
***with* J.M. Fenwick, W.H. Boyce, E. Brennan, J. Hopgood, S. Murphy, D.J. Williams, L. Rogers, J. Christensen, E. Riggs, T. Collins, C. Featherstone and G. Jones**

17:10 - 17:30
Urban Geology
E. BRENNAN, E. Brennan & Associates, Brisbane

CHAIR : **SUMMARY and VOTE OF THANKS**

QUESTION TIME

19:00 **SYMPOSIUM DINNER in the McLARTY ROOM, UNIVERSITY UNION**

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SUNDAY 25th March, 1990

TECHNICAL SESSION 8

LECTURE THEATRE E01

CHAIR : S.St.J. Warne

09:00 - 09:30

P-wave velocity in a Sydney Basin coal : dependence on confining pressure and water saturation

G. Yu, K. Vozoff & D.W. Durney
Macquarie University

09:30 - 10:00

Specifications and sources of rock in the Lower Hunter region suitable for marine and river works :

J. Braybrooke, R.J. Carr & F. MacGregor
D.J. Douglas & Partners

10:00 - 10:30

A SEM study of the conchoidal markings on quartz grains :

G. Li
University of Newcastle

CHAIR : SUMMARY and VOTE OF THANKS

TECHNICAL SESSION 9

LECTURE THEATRE B01

CHAIR : A. Hutton

09:00 - 09:30

Damped co-oscillating tide theory for the Georges River and calculation of the eddy diffusivities :

I. Mumme
CSIRO Div. Energy Chemistry

09:30 - 10:00

Measurements of soil erosion in the Sydney - Hunter Valley region :
R.J. Loughran[1], G.L. Elliott[2] & B.L. Campbell
[1] University of Newcastle
[2] Soil Conservation Service
[3] ANSTO, Lucas Heights

10:00 - 10:30

Structural trends in the Upper Narrabeen Group

P. J. Crozier
D.J. Douglas & Partners

CHAIR : SUMMARY and VOTE OF THANKS

10:30 - 11:00 MORNING TEA in the foyer of the GREAT HALL

TECHNICAL SESSION 10

LECTURE THEATRE E01

CHAIR : J. Braybrooke

11:00 - 11:30

Image analysis of char from pyrolysed lithotype concentrates :

J. Bailey
University of Newcastle

11:30 - 12:00

The radio imaging method – cases and capabilities

S. Thompson
METS Pty. Ltd

12:00 - 12:30

A geophysical study of the Gunnedah Basin, New South Wales :

I.Qureshi[1], R.A.Spencer[2] E.D.Tyne[2]
[1] Univ NSW [2] Dept. Mins & Energy

CHAIR : SUMMARY and VOTE OF THANKS

TECHNICAL SESSION 11

LECTURE THEATRE B01

CHAIR : Konrad Moelle

11:00 - 11:30

Exhalative minerals derived from coal and associated kaolinitic strata at Burning Mountain, Hunter Valley, NSW

F.I. Roberts & F.C.Loughnan
University of New South Wales

11:30 - 12:00

Gas ignitability by frictional effects from Australian coal mine rocks

C.R. Ward, A. Crouch, D. Panich & S. Schaller
University of New South Wales

12:00 - 12:30

Physical and chemical considerations in the conjunctive use of the Tomago Sand Beds aquifer for mineral sands mining and groundwater harvesting :

S.R. Jones, R.J. Carr & M.J. Thom
D.J. Douglas & Partners

CHAIR : SUMMARY and VOTE OF THANKS

STRUCTURAL ELEMENTS OF THE HUNTER COALFIELD : A PRELIMINARY ASSESSMENT

T.P.T. McLENNAN & E.M. LOHE
CSIRO Division of Geomechanics

INTRODUCTION

The post-depositional structural fabric of the Hunter Valley region and its associated coalfields reflects to a large degree a history of structural deformation characteristic of thrust-belt foreland regions. As such, it is not surprising that much of the surfical structural grain of the region is dominated by deformational fabrics characteristic of compression as a result of crustal shortening, eg. open folds and accompanying reverse, thrust faults and normal faults. As well, the coalfields region contains a number of significant structural elements whose origin may be related to crustal extension.

The aim of this paper is to discuss the character and geometry of some of the significant and salient structural elements of the region and to categorise regional structural domains within the Hunter Valley.

GEOLOGICAL SETTING

The Sydney Basin forms the southern section of the larger Permo-Triassic Bowen-Gunnedah-Sydney Basin system which extends from central Queensland to southern New South Wales. A number of possible tectonic models have been proposed for the origin of the basin including rift initiated foredeep (Scheibner, 1974, 1976), strike-slip initiated pull-apart basin (Harrington & Korsch, 1979), and a foreland retroarc basin (Murray, 1985). The most recently proposed model has been that of upper-plate crustal extension (Mallett et al, 1988).

The Hunter Coalfield region discussed here is part of the northeastern structural subdivision of the Sydney Basin described as the Hunter Valley Dome Belt (Bembrick et al. 1980). It forms a northwest trending belt of Permian coal-bearing rocks which cropout between the Carboniferous sequence of the New England Fold Belt to the north and the relatively flat-lying Triassic cover sequence of the Sydney Basin to the south. The northeastern boundary of the Coalfields is presently defined by the Hunter Thrust system which forms the leading edge of the thrust terrane of the NEFB. The southern margin of the belt is marked by the Triassic escarpment (Figure 1).

The structural fabric of the Hunter Valley region is characterised by a series of northerly-trending fold structures (monoclines, anticlines and synclines) with associated meridional normal faults (Mayne et. al. 1974). Many of these features eg., the Muswellbrook, Loder, Belford and Lochinvar Anticlines and the Mt. Ogilvie Fault, are recognised as being synsedimentary structures active during the Permian and to some degree the Triassic (Sniffin 1988). The meridonally trending faults are interpreted as basement structures which led to the formation of basement-controlled fault-blocks such as the Lochinvar Anticline (Rawlings & Moelle 1982).

PRINCIPAL STRUCTURAL FABRICS

During the course of this study, it has been recognised that the Hunter Coalfield can be divided into three principal structural domains; the western, central and eastern domains. These domains also correspond to the three general lithological and geological subdivisions of the coal mine groups (Figure 1) :-

1) **Group 1** mines, Greta Coal Measures, western domain.
2) **Group 2** mines, Vane Subgroup, central domain.
3) **Group 3** mines, Jerrys Plains, eastern domain.

The structural elements of these mine groups, in particular the main fault types, are listed below. The regional structural geology of the Hunter Valley Coalfield is characterised by 4 major groups of structural elements:

A) Thrust and reverse faults.
B) Fold structures: anticlines, synclines and monoclines.
C) Normal faults forming graben structures.
D) Other normal faults.

Group 1 Mines

Group 1 operating mines straddle the Muswellbrook Anticline (Figure 1). These mines win coal from the Early Permian Greta Coal Measures exposed along the crest of the anticline. At the northern end, the Muswellbrook Anticline crops out as a single closure. In the Bayswater-Drayton area, the anticlinal crest becomes a composite structure composed of several subsidiary fold structures which are subparallel to en-echelon the strike of the main hinge. The subsidiary structures appear not to be persistant along strike. The Muswellbrook Anticline area contains a several significant fault elements including thrust and normal faulting.

Thrust faulting observed in the Group 1 mines is considered to represent the influence of the Hunter Thrust System on the coal-bearing sequence of the Hunter Valley. In the Muswellbrook Mine area, the Branxton Formation of the Maitland Group is thrust to the southwest along the Aberdeen Thrust, up the eastern limb and over the axis of the Muswellbrook Anticline. In some places the fold axis is affected by overfolding to the west, and by foreland dipping and back thrusts. Until recently it was believed that the western limb of the anticline, on which the Muswellbrook Mine is located, was little affected by thrusting. However, it is now clear that on this limb the Greta Coal Measures have been affected to a considerable degree by thrust tectonism. Evidence for this style of deformation is characterised by bedding-parallel shear, thrust ramps and asymmetrical thrust folds. Vertical displacement across individual thrust planes affecting the western limb appears to be in the order of 20m or less. The amount of horizontal displacement involved has not been calculated. The direction of thrusting for this region, as indicated by mesoscale kinematic indicaters such as slickensides, asymmetry of small-scale folds and fold axes, and lateral thrust ramps is clearly from the NE.

Thrust related structures are also exposed along the eastern limb of the anticline to the south of the Muswellbrook area. At Drayton Mine, thrust faulting occurs in the East Pit area which is located on the easterly dipping limb of the Muswellbrook Anticline. Repetition of coal seams, in particular the Grasstrees G4 seam, by overthrusting was identified by mine geologists from drill-hole data. An area of repeated G4 seam bound by well-defined, high angle lateral ramp faults has been mapped in the northern area of the east pit. Thrust structures also locally displace igneous sills within the coal horizons in this area. Bedding-parallel shearing is locally common at various stratigraphic levels in the coal-bearing sequence in the region.

Movement indicators on these planes such as slickensides, small-scale fold asymmetry, fold axis orientation and the orientation of lateral ramps show that the direction of thrusting is from the NE.

Normal faults in the Muswellbrook Anticline region have orientations ranging from generally N-S (NNW to NNE), NW to WNW, and E-W. In the Muswellbrook region, the regionally significant St. Heliers Fault appears to be a normal fault which has down faulted to the east both the eastern limb of the Muswellbrook Anticline and the Aberdeen Thrust (J.Rogis, pers.comm.1989). Locally, fault-drag associated with movement on the St. Heliers Fault has caused significant rotation of the adjacent footwall and hanging wall rocks. In this northern area, normal faulting on the western limb of the Anticline is dominated by NW-WNW and locally meridional trending structures. These fault structures dip both directions and commonly have a "staircase fault" configuration, with the angle of the fault plane varying down dip. The dip of the fault plane appears to be locally related to and refracted by, the surronding lithology. Dips on these faults range from 55-65° on the steepest segments , and 35° or less on the shallowly dipping segments. Locally, segments of the faults are bed parallel.

In the central region of the Muswellbrook Anticline around the Drayton-Bayswater area two main scales of normal fault cropout: regional and local/mine scale structures. The regional scale structures are generally meridional trending fabrics which are subparallel to the axis of the Muswellbrook Anticline and commonly define areas of mining. These structures cropout along the western margin of the anticline and locally have displacements of upto 200m. Local or mine scale structures commonly strike NW and NE. Locally N-S and E-W trending structures are also evident. Mine-scale structures dominate the local structure along the western limb but also cropout along the hinge and locally on the eastern limb of the anticline. Faults are typically hinged, with maximum displacements at the centre of the structures. Displacements along mine-scale faults commonly range from 2-10m. Fault planes commonly dip 55-65° or less in either direction and may have a "staircase configuration". E-W trending normal faults form graben or horst and graben structures on the east and west limbs of the Muswellbrook Anticline. Subsiduary open-fold structures to the Muswellbrook Anticline locally crop out on the western limb. Fault-fold relationships suggest that these small-scale fold structures possibly formed at the same period as the local-scale normal faults.

Group 2 Mines

Group 2 mines lie adjacent to the eastern limb of the Muswellbrook Anticline. These mines are distributed across a series of generally NNW-trending broad, open fold structures, the Bayswater Syncline, the Camberwell Anticline and the Rix's Creek Syncline. Coal seams of both the Jerrys Plains and Vane Sub-Groups of the Late Permain Wittingham Coal Measures are mined in this region. The distribution of the coal-bearing sub-groups is essentially controlled by the sequence of anticlines and synclines. Apart from the folding, the three principal structural elements which characterise this domain and affect the geology of the mines are the Hebden Thrust, a relatively well defined northeast trending graben system locally termed the "Block Faulted Zone" (BFZ), and a NW trending zone of normal faults.

The Hebden Thrust is a subsidiary structure of the Hunter Thrust system. The influence of the Hebden Thrust is most clearly seen in those mines which are adjacent to it, the Foybrook and Swamp Creek Mines. At the Foybrook Mine, Maitland Group sediments are thrust to the SW, over the Vane Sub-Group coal-bearing sequence. The low angle thrust has dragged and locally overturned the sequence in the footwall. In the Swamp Creek Mine small localised thrust structures have been recorded. It is probable that thrust-related structures may be come more apparent as mining continues towards the footwall of the thrust.

The NE trending BFZ is a narrow zone of normal faults which traverses the coalfields from Swamp Creek in the north to Hunter Valley No.1 Mine in the south. This fault system has been identified in Hunter Valley No.1, Ravensworth No.2, Liddell C & A and Swamp Creek Mines. The zone is up to 500m wide, and essentially consists of an en-echelon array of inwardly dipping normal faults which define a series of horsts and grabens. The faults are commonly orientated at a slight easterly angle to the overall trend of the structure. Individual faults are not continuous along strike but vary in length from less than 100m to more than 500m. The faults are hinged and maximum displacement ranges from 0.4 to 15m.

The inter-relationship between the thrusting and these NE-trending normal faults clearly indicates that the normal faults postdate the main thrust faulting.

A NW-trending zone of large-scale normal faults crosscut the crest of the southeastern extension of the Muswellbrook Anticline. The fault system is best exposed in the Howick Mine area. The faults are relatively widely spaced with up to 1000m or more separation. As is typical of normal faults throughout the coalfields region, the fault displacement is variable along strike. Maximum displacements reach 20-30m on some faults.

Group 3 Mines

Group 3 Mines are located on the western flank of the Loder Anticline and the associated Mt. Thorley Monocline. These mines win coal from the Jerrys Plains Sub-Group which dips gently to the west off the monocline. Localised, subsidiary gentle fold structures occur in some areas, e.g. Warkworth Mine. The mines in this region are characterised by having relatively little structural deformation. However, this region does contain several distinctive structural elements including large scale normal faults and localised thrust and reverse faults.

Significant normal faults in this region are large-scale meridional trending structures which parallel the regional strike of the major fold structures. N-S orientated normal faults occur in several mines, e.g. Lemington and Mt. Thorley Mines. The dominant faults are westward dipping and may be related to basement faults associated with the formation of the formation of the Loder Anticline and the Mt. Thorley Monocline. Faults developed along the western edge of the crest of the Mt. Thorley Monocline are associated with significant drag. In the region of the Lemington Mine, steep easterly-dipping normal faults occur locally to the west of the larger westerly dipping fault. Small localised graben structures are developed in these areas.

Thrust faulting is presently recognised to be only locally developed throughout this region. To date no large-scale thrust structures have been recorded. Most of the thrust faults trend NE, and dip to the NW, suggesting a dominant, locallised transport direction from the NW. The thrusts are commonly small-scale, localised structures which do not exhibit large apparent displacements. Bedding-parallel shearing is locally evident in areas along the western limb of the Mt. Thorley Monocline, e.g. Saxonvale Mine. Shear sense indicators imply movement direction was from the west, up the limb of the monocline. The NE-trending reverse faults in this region may represent a discrete compressional event or be due to the refraction and reorientation of the regional principal stresses around inverted basement structures. The implied direction of maximum compression for these NE trending reverse structures is oriented NW-SE.

NW-trending thrust faults have been identified in several areas well into the foreland region of the coalfields, south of the main Hunter Thrust front. NW striking, SW over NE reverse thrusts cropout in a shale-rich sequence of the Triassic Narabeen Group at Howes Valley. The regional distribution of these thrust faults indicate that the effects of the Hunter Thrust compressional tectonism can be found across the Hunter Valley. However, the intensity of upper-crustal shortening appears to decrease away from the main thrust system.

CONCLUSIONS

The gross post-depositional structural fabric of the Hunter Valley Coalfields can be divided into the three broad structural domains on the basis of fold and fault types and geometries. These domains define regions of similar structural fabric and character. Thrusting has been found to be far more wide spread in the Permian coal-bearing sequence in the Hunter Valley than previously recognised. Thrusting is also recognised to affect the Triassic Narabeen Group sediments as far south as Howes Valley, to the south of the Hunter Valley.

The domain boundaries set out here are not absolute. Overlap of the structural fabrics along the boundaries will occur. This will probably be most evident in the region adjacent to the front of the Hunter Thrust where thrust faulting will be an important consideration.

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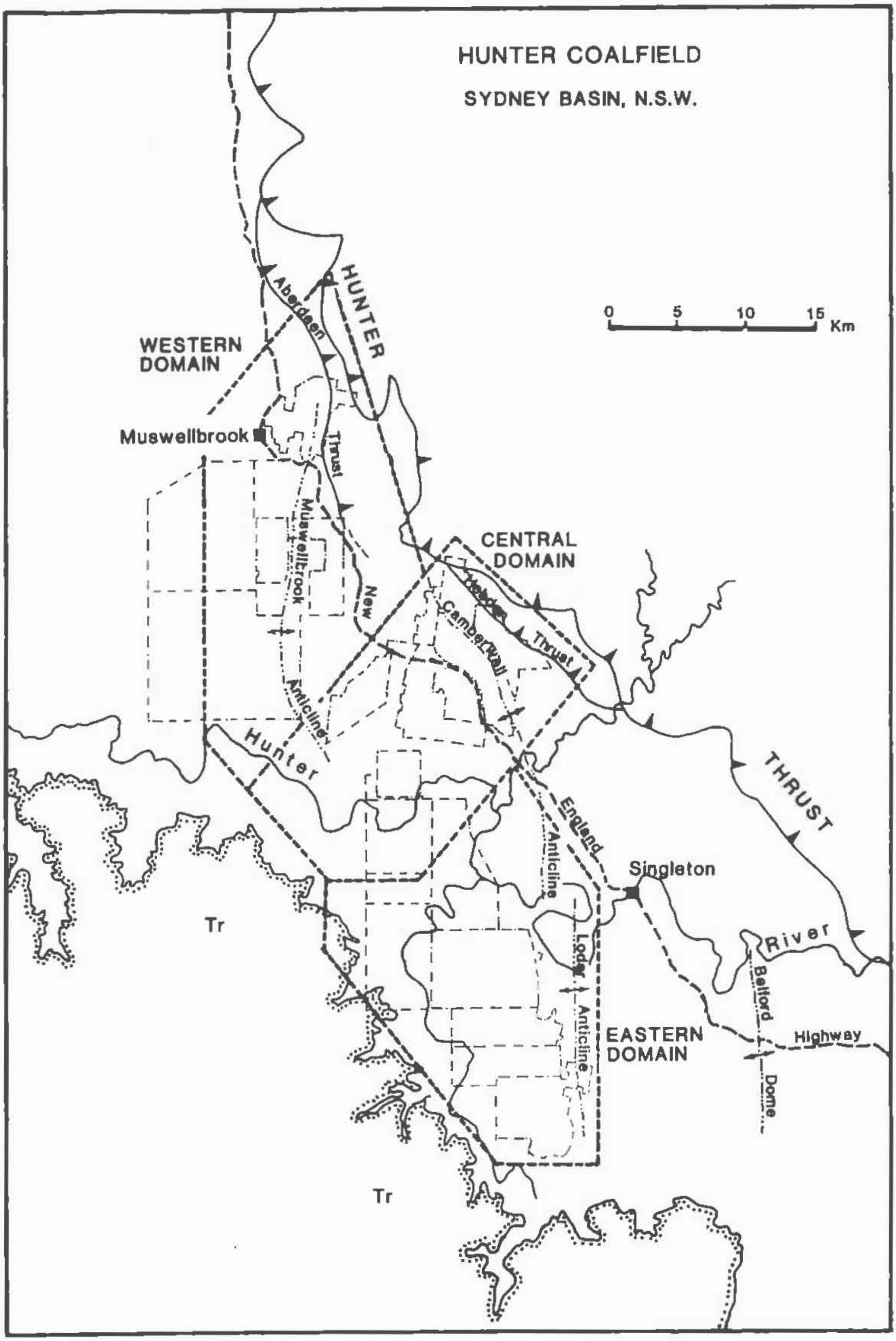

Figure 1. Map of Hunter Coalfield, showing three broad structural domains (Western, Central, and Eastern) subdividing the coal-mining areas.

A REINTERPRETATION OF PERMIAN TECTONISM IN THE SYDNEY BASIN AND SOUTHERN NEW ENGLAND FOLD BELT

W.J. COLLINS
University of Newcastle

INTRODUCTION

The effects of the Hunter-Bowen Orogeny (Carey & Browne 1939) in the Southern New England Fold Belt (SNEFB) and Sydney Basin are critically reviewed using previous stratigraphic and structural data, and recent isotopic results. In the past, the two tectonic environments have been considered as separate entities, but once it is realised that the Carboniferous arc-flank and fore-arc basin (the Tamworth Belt) is the substrate to much of the Permian Sydney Basin, as originally suggested by Osborne (1950), syndepositional tectonics within the latter can be used as a sensitive indicator for younger structural events in the former.

An attempt is made here to correlate regional-scale structures associated with Permian tectonism in the SNEFB and Sydney Basin, and use overprinting criteria to erect a deformational history; the correlation is a contrary interpretation to previous models. In particular, early meridional folds, which are common to both tectonic environments, are truncated, rotated and appressed by the Peel Manning Fault System (PMFS) in the eastern part of the Tamworth Belt. This suggests that the Hunter-Mooki Thrust System (Carey & Osborne 1939) pre-dates the PMFS, implying that the latter formed in the Late Permian, not in the Late Carboniferous as suggested previously.

REGIONAL GEOLOGY

The SNEFB, part of the New England Eugeosyncline of Voisey (1959), has been subdivided into 2 major tectonic zones, an arc-flank and fore-arc basin (Zone A of Leitch 1974) and a subduction/accretion complex (Zone B of Leitch 1974), called the Tamworth Belt and Tablelands Complex, respectively (eg. Roberts & Engel 1987). The Sydney Basin is in faulted contact with the Tamworth Belt, along the Hunter-Mooki Thrust System (HMTS), but in the SE, near Maitland, sediments of the basin overlap those of the belt (see below).

Relationship between the Sydney Basin and the SNEFB: A Change from Subduction/Accretion to Back-arc Rifting.

Permian sequences in the Sydney Basin and Tamworth Belt overlie Carboniferous rocks conformably, disconformably or with slight angular unconformity. Osborne (1950) first demonstrated conformable relationships, noting that the boundary between the Carboniferous and

Permian systems was one of "overlap, more or less progressive in character" (p.15, Osborne 1950). This is best seen in the Maitland area, at the SE termination of the HMTS, where the thrust dies out in the Oakhampton Syncline (Gale 1980). Directly northward, Carboniferous strata of the Seaham Formation pass conformably into Permian sequences (Osborne 1950), equivalent to the Dalwood Group of the Sydney Basin. In the Pokolbin and Cranky Corner areas, Carboniferous sediments are also conformable with the overlying Dalwood Group (Brakel 1972; Osborne 1950; McClung 1980)

In places, a disconformity or slight angular unconformity exists at the Permo-Carboniferous boundary, but stratigraphic breaks are typical of the Carboniferous and should not be accorded special significance as they are a general characteristic of volcanic arc terrains. Reiterating Carey's (1934) original assessment for the Werrie Basin, McPhie (1982) stated, "the relationship between the Carboniferous and Permian units is one of onlap of the latter over a landscape of subdued relief underlain by the former". This is of general applicability and indicates that, for the early history of the Permian at least, the Sydney Basin was the same structural entity as the southern Tamworth Belt.

Of greater significance is the change in style of volcanism in the Early Permian. After a systematic change in Carboniferous volcanism, from intermediate to silicic (Leitch 1974), typical of arc maturation, volcanism in the Early Permian was dominantly mafic or bimodal, heralding the onset of sedimentation in the Sydney and Werrie basins and the Gloucester Syncline. Rocks of the Early Permian Warrigundi Igneous Complex, which are Werrie Basalt equivalents, have considerably lower initial Sr^{87}/Sr^{86} ratios than the Carboniferous volcanics, indicative of a mantle source with little crustal contamination, tapped during crustal thinning (Flood *et al* 1988).

Isopach maps of the northern Sydney Basin during Greta Coal Measure and early Maitland Group times suggest deposition was confined to the southern margin of a meridional trough (Mayne *et al* 1974), similar to the Gloucester Syncline, where syndepositional normal faults attest to rifting of the relic arc in the Early Permian (Lennox & Wilcock 1985). Volcanic clasts in Sydney Basin conglomerates were initially derived from the north, systematically progressing to a NE provenance in the Late Permian, and ultimately derived from a volcanic source farther to the E in the Triassic (Conaghan *et al* 1982). Relics of the eastward Permo-Triassic arc are the Gympie Province (Day *et al* 1978). The Sydney Basin, therefore, is considered to have initially formed in a back-arc or "retro-arc" environment, as initially suggested by Schiebner (1976).

A REINTERPRETATION OF THE HUNTER-BOWEN OROGENY.

The "orogeny" is subdivided into four events for clarity, but it should be stressed that the events follow one another as a natural consequence of progressive large-scale deformation, but some are reversed from previous workers' interpretations (Osborne 1950; Gale 1980; Roberts & Engel 1987).

PERMIAN TECTONISM

D_1 Deformation (Fig. 1a)

Meridional folds developed throughout the Tamworth Belt and Sydney Basin in response to regional E-W compression (Osborne 1950), producing the Gloucester and Werrie synclines and the Lochinvar, Muswellbrook and Timor anticlines. The Lochinvar Anticline was rising during deposition, and therefore is a sensitive indicator of the F_1 folding history in the Sydney Basin. Folding climaxed and terminated late in Tomago Coal Measures time, and is represented by the upper Tomago Coal Measures angular unconformity on the eastern flank of the Anticline (Blayden 1971; Diessel 1980). Locally, the discordance is up to 30^0 (Blayden 1971), but farther east it rapidly diminishes (Diessel 1989. pers. comm.).

D_2 Deformation (Fig. 1b)

Continued compression resulted in the propagation of thrusts and fault-related folds in the Tamworth Belt, producing a series of shallowly-inclined imbricate thrusts and open NW-trending folds (Roberts & Engel 1987). These are the border thrusts described by Voisey (1959). In the adjacent Sydney Basin, dome-and-basin structures also represent fault-propagated folds generated by lateral and oblique ramping of floor thrusts (Glen & Beckett 1989).

The most important of the "border thrusts" is the Hunter-Mooki System (HMTS) of Carey & Osborne (1939), which extends some 300 km or so, in an arcuate belt running subparallel to the Peel-Manning Fault System NE of Muswellbrook (Fig. 1b), propagation of shallowly inclined imbricate thrusts, dipping 13-14^0 east (Roberts & Engel 1987), has resulted in stratigraphic repetition of Upper Carboniferous sequences (Roberts & Engel 1987).

Strike-slip tear faults in the Murrurundi region form a conjugate system associated with the HMTS, indicating the effective compressive stress directions during thrusting were NE-SW (Fig.1b). The apparent anticlockwise rotation in stress direction relative to D_1 orientations can be explained by a progressive change from E-W coaxial deformation to E-W non-coaxial deformation associated with a sinistral shear couple, as originally noted by Carey (1934). The stress directions are consistent with those determined independently by Gale (1980) for movement on the Hunter Thrust, 100km to the south near Maitland.

A series of low amplitude folds developed near the leading edge of the Hunter Thrust sheet (Roberts & Engel 1987) in response to the inferred listric geometry of the thrust; at their termination, thrusts typically curve upward, requiring that a set of folds develop parallel to the fault margin as "accommodation structures". Alternatively, they may represent folds associated with ramps in the HMTS (Glen & Beckett 1989). These F_2 folds refold F_1 meridional folds, producing typical Type 1 interference patterns which formed the Cranky Corner and Mindaribba basins.

D_3 Deformation (Fig. 1c).

A series of meridional faults developed in the southern Tamworth Belt, most of which are considered to be backthrusts on the upper (allochthonous) plate of the Hunter Thrust. The faults swing to the SE as the thrust is approached, but never extend beyond it; some terminate before it is reached. The faults are best developed between Singleton and Dungog, and include the Webbers Creek, Lennoxton, Hungary Hill, Butterwick (Osborne 1950), and Karrakurra and Camyr Allyn faults (Roberts & Engel 1987). Most of these faults show downthrow to the east and thus have been considered as normal (Gale 1980; Roberts & Engel 1987), but only the Webbers Creek Fault is described in detail; it is W-dipping reverse (Gale 1980), consistent with a 'backthrust' origin on a thin upper plate. That most of the faults are subvertical, with displacement decreasing towards the thrust margin, and with a "west-up" movement, are all features of "stress relief" (Osborne 1950; Gale 1980) on a thin overthrust sheet during backthrusting.

The Williams River and Tarean faults might also have developed at this stage, but have undergone reactivation during D_4.

D_4 Deformation (Fig. 1d).

Sinistral shear culminated in the Peel Manning Fault System (PMFS), leading to displacements possibly in the order of hundreds of kilometres. It was preceded by anticlockwise rotation of F_1 folds in the Myall region and probably by similar rotation and emplacement of the Hastings Block to its present position in the Tablelands Complex.

In the Myall region, most of the faults are E-dipping reverse structures that strike to the NW and twist further W as the PMFS is approached. They are best developed near the PMFS and dissipate in intensity and diminish in displacement to the SE where some, such as the Waukivory Fault, die out altogether. These faults are also responsible for tightening F_1 folds and locally overturning F_1 limbs. Most importantly, these faults are responsible for truncating and rotating D_1 fold traces from meridional to northwesterly. For example, the Gloucester Syncline is truncated by the Mograni Fault, and the Myall Syncline by the Waukivory Fault. From the Gloucester Syncline in the west to the easternmost outcrops at the coast, there is a progressive anticlockwise block rotation from N-S to NW-SE, representing a swing of $\tilde{}45^0$. Westward from the Williams River Fault, the intensity of deformation decreases rapidly (Roberts & Engel 1987).

The PMFS has been regarded by most recent workers as a Late Carboniferous-Early Permian structure, relating it with terminal subduction and emplacement of $\tilde{}280$ Ma old serpentinites (Lanphere & Hockley 1976). However, a maximum Early Permian age is constrained by the presence of Artkinsian-Sakmarian faunas in fault blocks associated with the PMFS (Price 1973). Truncation of F_1 folds by the PMFS, such as the Gloucester Syncline, suggests major movement was Late Permian. Interestingly, Osborne (1950) implied that PMFS movement occurred late in the Permian, during the Hunter-Bowen Orogeny.

Studies on S/C mylonitic fabrics in the serpentinites indicate several movements, but the most important is sinistral (Offler & Williams 1987). That most of the movement is strike-slip is indicated by only minor metamorphic grade changes across the PMFS (Offler & Hand 1988). Large curved faults splay northward off the PMFS, separating the major tectonostratigraphic units of the Tablelands Complex, and are the result of the Permian dispersal (Cawood & Leitch 1985). These faults also require large strike-slip displacements, and are considered subsidiary to the PMFS.

PERMIAN TECTONISM

Geochronological Constraints

Precise radiometric dates for specific rock-units in the SNEFB and Sydney Basin are lacking, and an absolute time-scale of structural events can only be tentatively erected. Nonetheless, an attempt is necessary to so that deformation events in the SNEFB can be directly correlated with those elsewhere.

The recent dating programme of Gulson *et al* (1990) highlighted several important issues relating to the Permian time-scale, at least for eastern Australia: i) the data strongly suggest that the Permo-Carboniferous boundary is ~300 Ma and the Permo-Triassic boundary is ~255 Ma; ii) conservative estimates of average deposition rates throughout the Permian of the Sydney Basin are 65 metres/ Ma; on this basis, the Early\Late Permian boundary, corresponding to "Muree Stage" in the Sydney Basin, is ~280 Ma. Although somewhat artificial in that it does not account for changing deposition rates in different environments, the maximum error limits for rock units can only be ± 5 Ma, typical of errors associated with most radiometric age determinations for the SNEFB.

Several important implications, based on Gulson *et al* (1990), are:

(1) The commencement of the Hunter-Bowen Orogeny was heralded by movement on the Lochinvar Anticline, a sensitive measure of D_1 timing, at ~280 Ma (Muree Stage) and continued to Upper Tomago time; it probably culminated during the later stages, indicated by the angular unconformity (up to 30^0) within the Tomago Coal Measures. 50m below the unconformity, the Thornton Claystone is precisely dated at 266 ± 1 Ma (Gulson *et al* 1990). Based on the 65m/Ma sedimentation rate inferred by Gulson *et al* (1990), movement of the Anticline terminated at ~265 Ma. Therefore, the orogeny began (D1) in the Late Permian.

(2) The Hunter Thrust cuts the Lochinvar Anticline, and is therefore younger than 265 Ma.

(3) The Hunter Thrust also cuts Wittingham\Tomago Coal Measures and terminates to the SE, near Maitland. Beyond, there are no SE-NW trending folds in the Newcastle Coal Measures, only N- to NE-trending Macquarie Syncline and subsidiary folds (Diessel 1980). Thrusting does not appear to have affected the Newcastle Coal Measures.

(4) A precise age on Hunter thrusting is not possible because younger rocks are not in contact with the fault. This could indicate that thrusting occurred during Newcastle Coal Measure time, though isopach maps suggest that during deposition of the marine Waratah Sandstone, the basin extended farther northward (Mayne *et al* 1974), beyond the fault trace. Therefore, thrusting probably post-dated Waratah Sandstone deposition.

(5) Rapid uplift of the Tamworth Belt is recorded by numerous fanglomerates of the Newcastle Coal Measures; this depositional episode was the most extensive of the Permian regressions, characterised by fanglomerate deposition, and maximum thickness of sediment was accumulated adjacent to the Hunter Thrust (Herbert 1980). At this stage, the Sydney Basin evolved from a rift- to a foreland-basin; the northerly provenance of the fanglomerates (Rattigan & McKenzie 1969) is consistent with substantial uplift of the relict arc at this time, directly after movement on the Hunter Thrust. Sediment accumulation was thickest in the "foredeep" adjacent to the HMTS (Herbert 1980), representing the culmination of the sedimentary megacycle of Conaghan *et al* (1982).

Deposition of the upper Newcastle Coal Measures, therefore, is considered to be the initial sedimentological response to Hunter Thrust movement.

(6) Thrusting is considered to immediately follow termination of meridional folding as bulk strain associated with E-W compression was partitioned into discrete fault zones. The thrust is therefore considered to have developed between late Tomago/ early Newcastle coal measure time, at 265-260 Ma.

(7) Backthrusting (D_3) followed immediately after emplacement of the main upper sheet bounded by the Hunter Thrust.

(8) The PMFS postdated the HMTS, but predated Moonbi Suite intrusion (255-245 Ma).

(9) The orocline folds the PMFS and must therefore be <u>younger</u> than 265 Ma, the maximum age of the PMFS. However, it must also have predated the 255-245 Ma I-type plutons, which are post-tectonic.

CONCLUSIONS

All the Late Permian deformation structures in the SNEFB, excluding oroclinal bending, can be ascribed to a single, but complex compressive tectonic event, the Hunter-Bowen Orogeny (Carey & Browne 1939). These authors considered that the complex patterns of faults at the leading edge of the Hunter Thrust related to impressed sinistral shear stress. This explanation applies equally well to the PMFS and associated splay faults in the Tablelands Complex, during the latter stages of the "orogeny".

Initial E-W orientated coaxial deformation in the early Late Permian produced a series of meridional folds and subparallel faults (D_1). Imbricate thrusting followed (D_2), culminating in the SW-directed Hunter Thrust; here, the effective principal stress direction was NE-SW, the direction applied if deformation evolved into non-coaxial sinistral shear during E-W compression. The regional nature of SW-directed thrusting implies very large scale deformation. E-W directed stress release on the upper, allochthonous plate of the Hunter Thrust resulted in the development of meridional backthrusts, and probably normal faults (D_3). Note the reversion to E-W stress orientations, indicate by the N-S strike of D_3 backthrusts, rather than NW-SE, parallel to the imbricate thrusts.

The final major deformation (D_4) reactivated D_3 meridional faults and rotated fault blocks anticlockwise in the Myall region of the Tamworth Belt, and caused anticlockwise rotation and sinistral translation of blocks in the Tablelands Complex. It also resulted in mass movement of the entire Tablelands Complex from the SE, effectively removing the complete northern extension of the Carboniferous magmatic- and fore-arc. The operating stress field might have been E-W, though many of the splay faults should then show substantial reverse movement. Alternatively, the principal stress vectors rotated to the SE, applying oblique (sinistral) compression on the SNEFB. A detailed analysis of the major splay faults in the Tablelands Complex should resolve the issue.

The entire orogenic cycle, starting with climactic folding of the Lochinvar Anticline in Tomago times and terminating with dispersal of tectonostratigraphic blocks in the Late Permian-Early Triassic, is recorded as a massive flooding of the Sydney Basin with continental detritus, the Permo-Triassic megacycle of Conaghan *et al* (1982).

PERMIAN TECTONISM

Oroclinal bending followed, but cannot directly relate to the "Hunter Bowen Orogeny" as the "z" shaped geometry of the megafold indicates large-scale dextral motion (Flood & Fergusson 1982). It might relate to oblique dextral plate convergence (cf. Murray *et al* 1987), but if so, the event was Late Permian, not Late Carboniferous.

ACKNOWLEDGEMENTS

This project was funded by a Senate Research Committee grant from The University of Newcastle. Discussions with staff of the Geology Department, The University of Newcastle, are greatly appreciated. Permission to use pre-print material from Gulson *et al* (1990) is also gratefully acknowledged.

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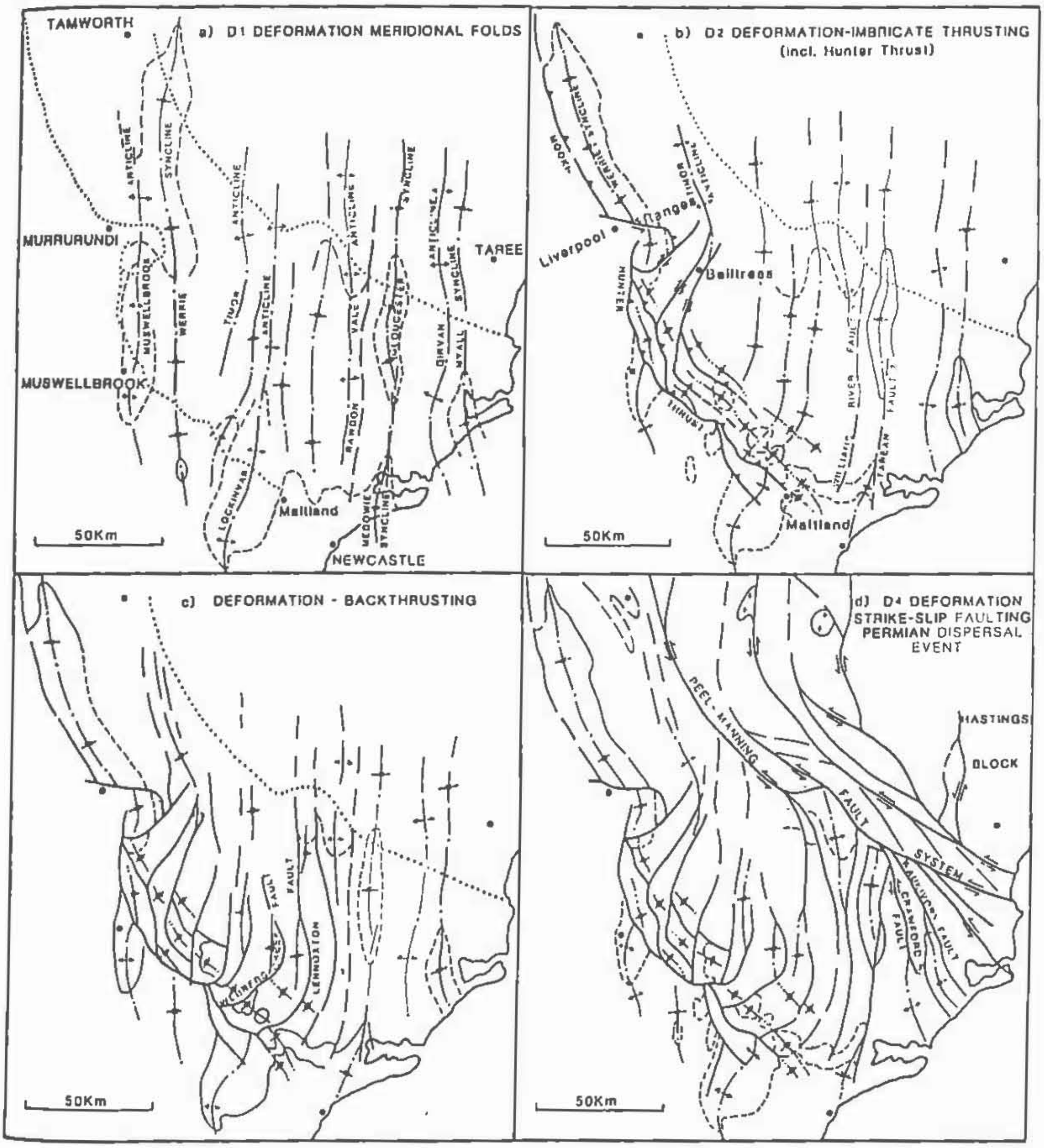
Figure 1. Diagram showing postulated tectonic evolution of the Southern England Fold Belt and Sydney Basin.



GEOPHYSICAL LOGS AND CORRELATION IN THE SOUTHERN SYDNEY BASIN

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INTRODUCTION

Many attempts have been made to correlate the stratigraphic units of the Illawarra Coal Measures in the Southern Coalfield with those in the Western Coalfield. Whereas most geologists would agree that this is feasible, few attempts if any, have satisfied all or even the majority of workers Working parties reviewing the nomenclature of the Illawarra Coal Measures in the Southern Sydney Basin have encountered several problems relating to the type sections as presently defined. Hutton (1989) outlined some of these problems which are again listed below:

i. several type sections are defined from what could be best termed marginal facies of the basin;
ii. several type sections have severely weathered and are of little use;
iii. some type sections defined from drill core which no longer exists;
iv. poor compatability between geologs and core;
v. core has deteriorated and is, at best, of dubious value; and
vi. descriptions of type sections fall short of those requirements under the stratigraphic nomenclature code.

One additional problem is an historically-related problem in that the type sections were defined before geophysical logs were commonly used. Most holes from recent drilling programs are now routinely logged and some of the geophysical logs appear to contradict boundary data given in the geological logs. For example, a rather sharp change in the response on a geophysical log may correlate with a gradational change on the litholog. Therefore a case can be argued that any change in the terms or stratigraphic boundaries of the type sections should take into account geophysical signatures, especially as many companies are routinely logging holes rather than coring.

This paper discusses preliminary results where geophysical logs are used to correlate units across the Southern Sydney Basin.

PREVIOUS STUDIES

Whilst many companies have used geophysical logs for various uses within a colliery holding, few have published basin-wide studies which incorporate geophysical logs. One such study was that of Arditto (1987a, 1987b and 1987c). Arditto's study focused mostly on well log and seismic sequence analysis and the implications for hydrocarbon exploration. Six depositional sequences or succession cycles were recognised with the base of the first at the base of the Broughton Formation of the Shoalhaven Group and the last with its base corresponding to a laterally extensive coarse sandstone near the top of the Eckersley Foramtion. Another sequence of Triassic age corresponded the Narrabeen Group.

Each sequence or succession cycle resulted from an eustatic cycle and was thought to have basin-wide significance.

The base of each sequence in the coal measures succession was marked by a coarse to pebbly sandstone with a sharp, erosional base (corresponding to an incised fluvial valley fill cycle) which was deposited after the initial erosive cycle of a rapid eustatic fall. Each cycle was an upward-fining sequence culminating in a coal unit. Each transgressive cycle corresponded to a thin marine progradational unit. The end of each transgression was marked by a condensed interval of highly bioturbated claystone-shale. Each condensed interval was overlain by an upwardly coarsening nearshore marine to coaly coastal plain unit or highstand cycle. The top of each genetic sequence was marked by an unconformity surface resulting from the next rapid eustatic fall.

The significance of Arditto's study is the recognition of boundaries on geophysical logs and locating these boundaries in the core. Arditto's study indicated the usefulness of geophysical logs and encouraged efforts to recognise the individual units within his sequence. The study was facilitated by a recent project which showed that correlation of units between the Southern and Western Coalfields was feasible.

STRATIGRAPHY OF THE SOUTHERN SYDNEY BASIN

The stratigraphy of the Southern Coalfield, as currently accepted by the Standing Committee on Coalfield Geology of New South Wales dates from the early 1970s and now appears to be obsolete, as a working party is now revising the stratigraphy. A preliminary draft is expected mid-year.

Detailed work by Hutton et al (1990) suggested that several new units should be recognised, especially some of the claystone units which contain abundant tuffaceous sediment. Some of the recommendations include:

i. formalising the volcanic units within the Pheasants Nest

Formation as published by Carr (1982);

ii. inclusion of the Marangaroo Conglomerate in the Southern Coalfield stratigraphy;

iii. recognition of the Bargo Claystone and Darkes Forest Sandstone as formal units;

iv. recognition of at least three tuffaceous units; and

v. inclusion of Loddon Sandstone Member as a formal unit.

Figures 1a and 1b shows part of one section given in Hutton et al (1990) to illustrate the correlation of units across the Southern Sydney Basin.

GEOPHYSICAL LOGS

With the revision of the stratigraphy of the Southern Sydney Basin and the increased use of geophysical logs, the need to consider correlating geophysical logs, lithologs and formal stratigraphic units has become evident.

Figures 2 and 3 show the gamma and density logs for two holes drilled in the Southern Sydney Basin. Figure 2 shows the logs for a hole drilled near a working Illawarra colliery whereas Figure 3 shows the logs of a hole drilled nearer to the centre of the basin.

In both holes the Bulli and Balgownie seams are well represented and are clearly defined on the density logs. However in Figure 2, the Balgownie seam has a distinctive clayey interval which is not clearly defined on the density log, probably because of the scale at which the log is presented. For holes drilled near the southern extremity of the Illawarra Coal Measures, such as in the Robertson area, the Bulli and Balgownie seams are absent or in some holes are represented by thin carbonaceous or coaly intervals.

In the Southern Coalfield the Wongawilli Coal interval is a composite of good quality coal, lower quality coal and dirt bands, especially where it is worked in the Illawarra area. On the gamma log (Figure 2) the dirt bands show up as clay-rich layers and in core these correspond to tuffaceous intervals. Nearer the central part of the basin the Wongawilli Coal is much thinner and comprises three coaly layers separated by tuffaceous layers. The lower coal layer, which is mined in the Illawarra area, is much reduced.

Just as important as the recognition and characterisation of the coal seams from geophysical logs is the information relating to the clastic intervals between the seams. The interval between the Bulli and Balgownie seams comprises a thick medium- to coarse-grained sandstone with two thin siltstone layers, as shown in Figure 2. Within the Illawarra area this is the typical occurrence of the unit, for which Hutton et al (1990) proposed the same Loddon Sandstone Member. Figure 3 shows that this interval comprises two substantial sandstone layers separated by a significant shale-siltstone layer.

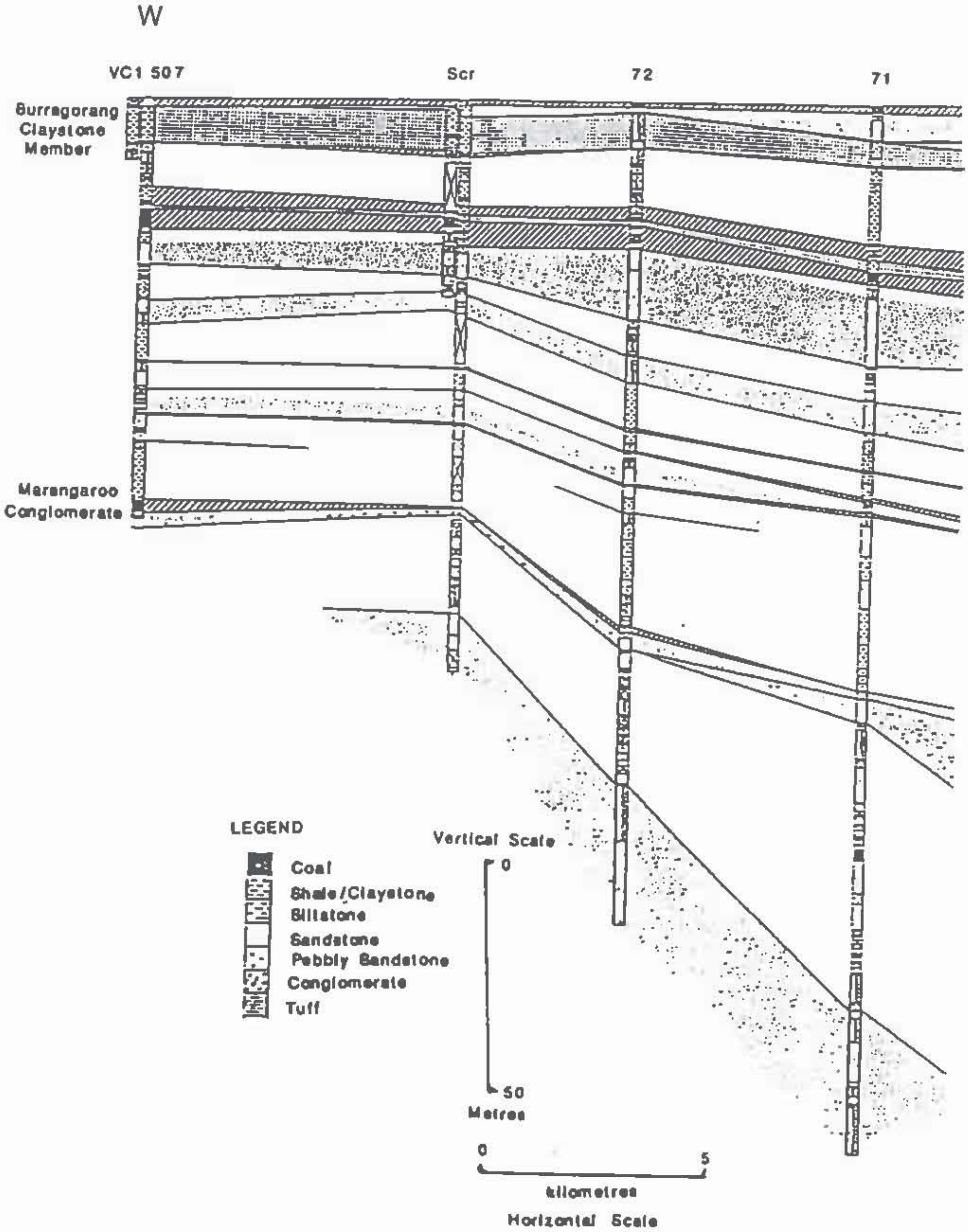

Figure 1a. Western end of a cross section through the Illawarra Coal Measures, Southern Coalfield.

Geophysical Logs and the Southern Coalfield

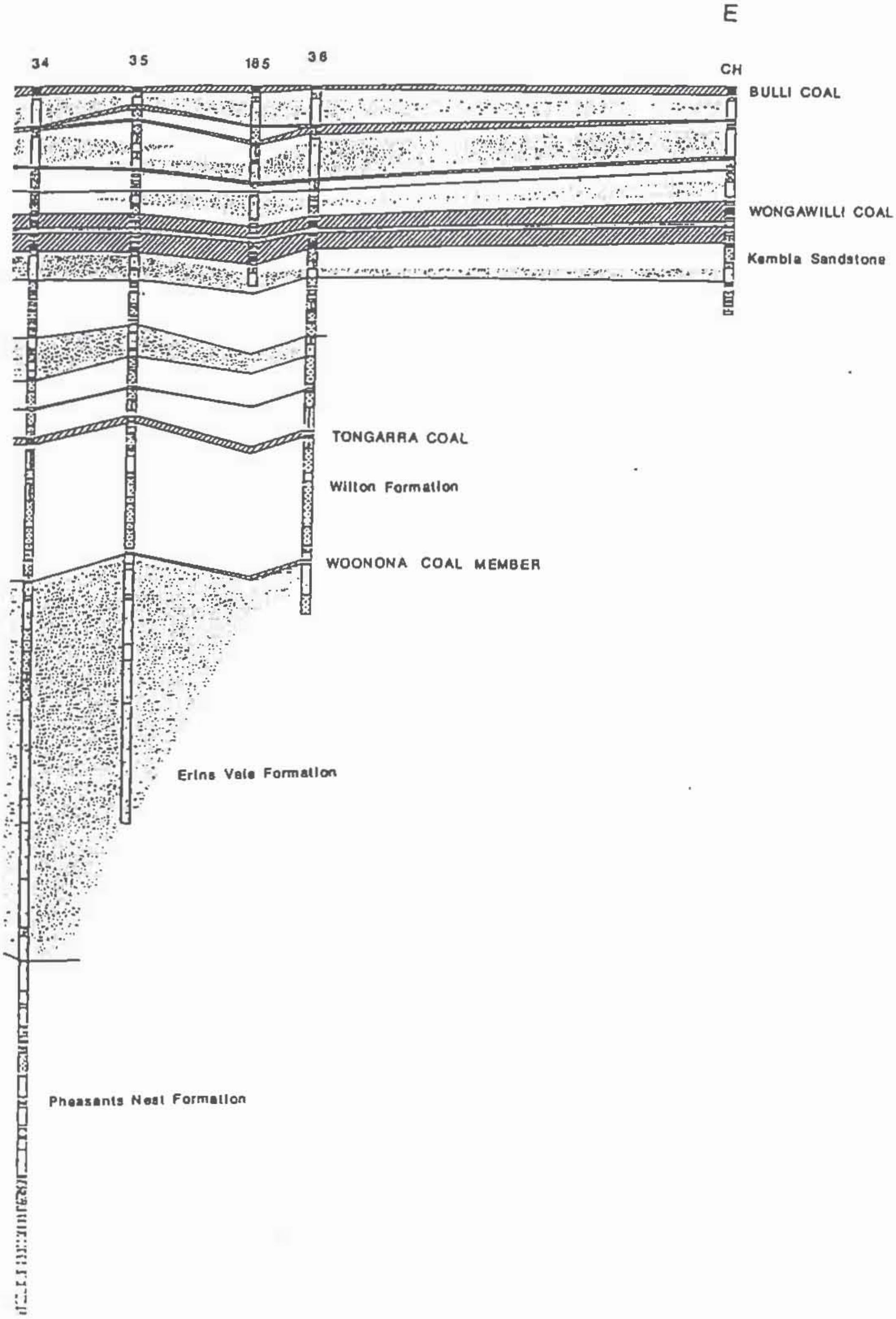

Figure 1b. Eastern end of a cross section through the Illawarra Coal Measures, Southern Coalfield. (from Hutton et al., 1990)

The clastic sequence between the Balgownie seam and the Wongawilli seam thickens towards the centre of the basin. Within this sequence, at least three coarsening-upward sequences can be recognised. Between the depths of 733 and 738 m two coarsening-upward units of approximately two metres thickness occur. Above these, starting at a depth of 732 m is a ten metre coarsening-upward sequence with terminates with a thin coal.

SUMMARY

Geophysical logs are an extremely useful tool for characterising coal measures sequences in the Southern Coalfield. With increases in drilling costs, companies are likely to rely greatly on geophysical logging rather than coring. In addition, the cost of storing core is increasing and many companies no longer retain core for extended periods. Consequently geophysical logs will be one of the main sources of information when future generations of geologists wish to re-evaluate drill holes for which core is no longer available.

With the increase in the availability of geophysical logs it is now possible to produce reference geophysical sections to match reference cross sections constructed for the Southern Coalfield.

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Geophysical Logs and the Southern Coalfield

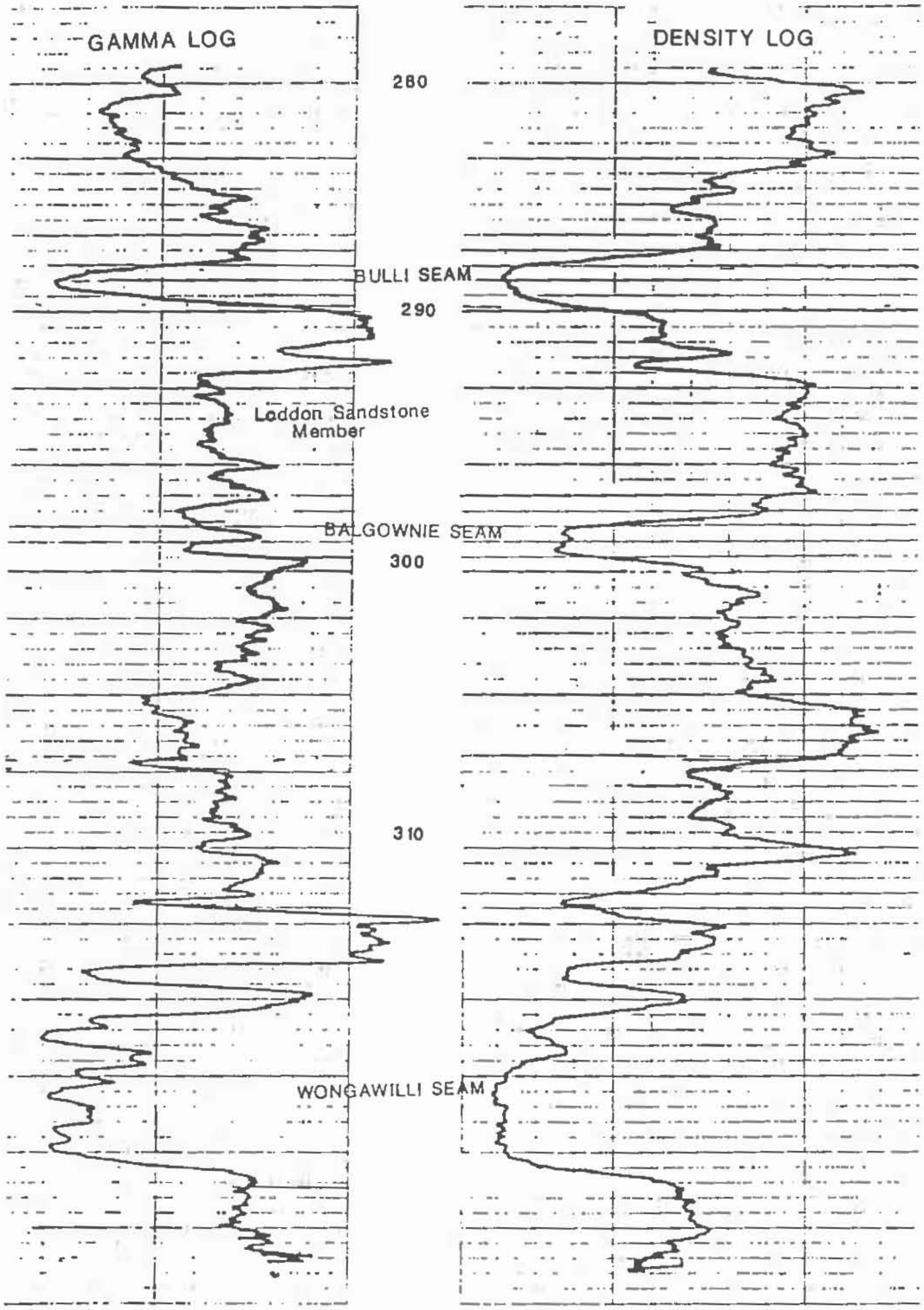

Figure 2. Gamma and Density logs for a hole near Wollongong.

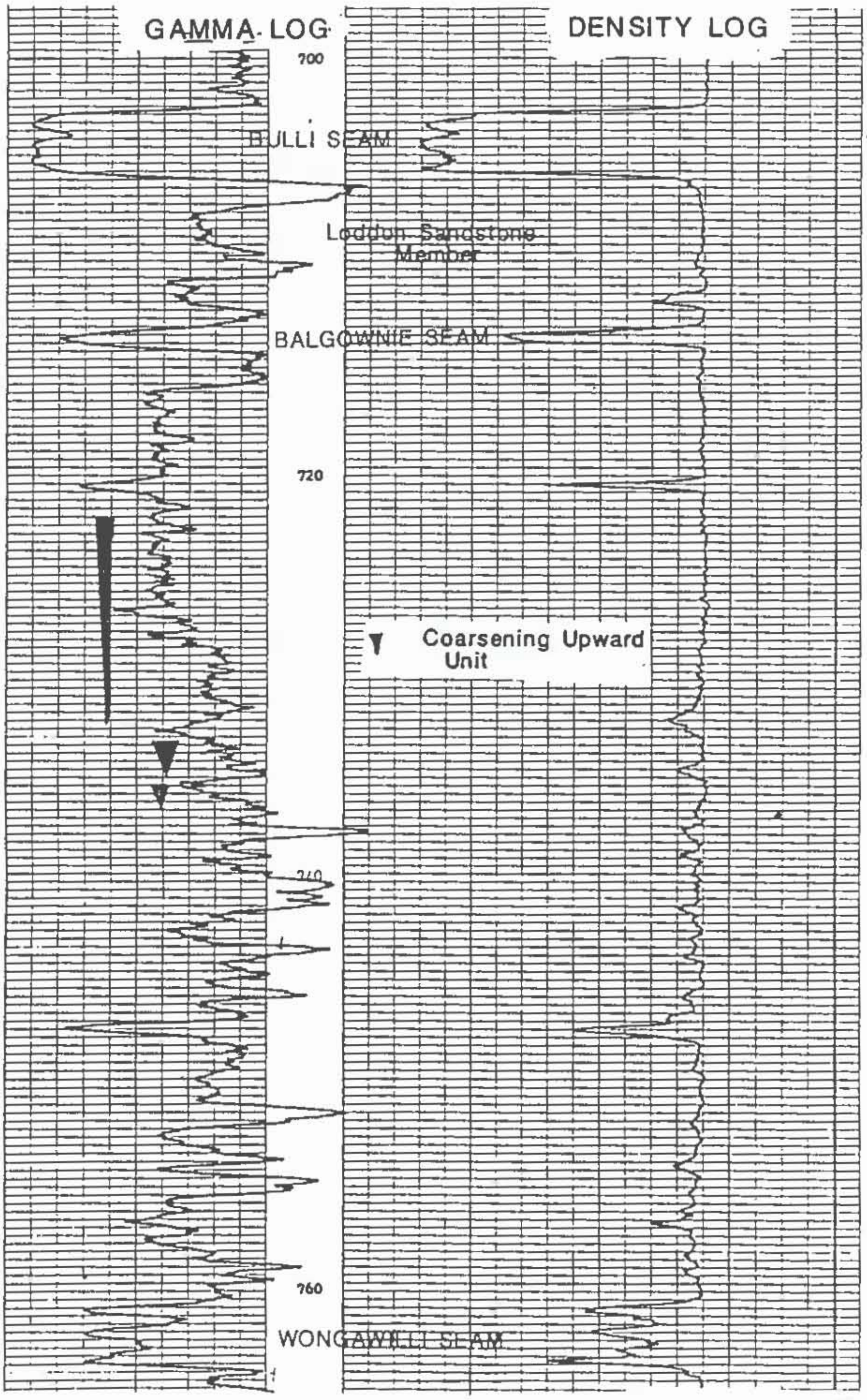

Figure 3. Gamma and Density logs for a hole, northwest of Campbelltown.

APPLICATION OF HIGH RESOLUTION SEISMIC PREDICTIONS TO MINING – A CASE HISTORY

J. HANES & P. MADDOCKS
BHP Collieries, Wollongong

INTRODUCTION

This paper summarises the results of high resolution seismic (HRS) surveys conducted at Appin Colliery in the Southern Coalfield and describes and illustrates anomalies. The conduct of the surveys was reported by Hanes et al, 1989. The objective of the paper is to promote understanding of the potential and limitations of the technique and of the levels of confidence which can be placed on various interpretations.

High resolution seismic was used at Appin Colliey in 1986, 1987 and 1988 to define coal seam structures ahead of mining. Work to date has had varying degrees of success. The technique can reliably identify faults with displacements as small as 5 m to 10 m in areas of good quality data, but resolution and reliability decrease with data quality. Seismic anomalies require confirmation by physical means such as drilling or mining.

The ability to confidently interpret small structures improves with time spent on evaluations, the mining of predicted structures and the constant reevaluation of the data as new evidence becomes available from mining or drilling. Important technological advances which can improve data quality are made with each new survey. The potential for advanced interactive computer assisted interpretation in the near future should reduce the large time requirement for interpretation while allowing investigation of more structural configurations.

SEISMIC SURVEYS RESULTS

The quality of seismic record varies considerably. As is to be expected there is a deterioration towards the line ends with decreasing fold. Similarly in structurally disturbed zones the record is understandably poor. Also quite large areas exist from which little or no signal is returned from the coal seams. Where seismic records are produced as continuous unbroken lines, it can be confidently concluded that no structure of +5m displacement exists. This has been proven over longwalls 16 and 17 which were shown by the 1986 survey to be free of +5m structures (Figure 1).

Some licence is applied by geologists on interpreting structures and some smaller features are interpreted as low confidence structures in places where a geophysicist would be professionally restricted to interpret a structure. The purpose of this is to give a warning of a potential hazard so that further reevaluation can be made as extra data become availabe on mining or drilling. The chances of success with these predictions are low, but can be improved with experience gained through mining of low confidence structures. The philosophy adopted is that "forewarned is forearmed".

Figure 1 shows several features interpreted as anomalous seismic records potentially interpretable as geological structures.

The 1986 survey indicated that Longwalls 16 and 17 were free from detectable structures with good seismic record produced. Southeast of these longwalls, the record quality deteriorated to very poor with numerous possible complex structures. The major fault was detected but not delineated confidently. Parts of the 1986 lines were interpreted as being over faulted ground or the lines were parallel to faults. This interpretation was confirmed by the 1987 survey. Features indicated by the 1986 survey but not confirmed by immediately adjacent 1987 lines are considered spurious and nonexistent.

The 1987 survey was conducted over lines oriented and spaced to confirm structures indicated by the 1986 survey. Considerable areas free from hazards were indicated in Longwall 18 and in other areas to the southeast. Several structures varying from high to low confidence were indicated. The major fault was confidently detected on 18 lines giving good resolution of its location and complex nature. Representative profiles across the fault are shown in the figures. The fault was interpreted as changing strike and character in the middle of the area. This complexity was further investigated in 1988 with a 3D seismic trial survey which indicated the merging of two major faults (Hatherly and Poole, this volume). The fault was intersected by Brennan Panel beyond the survey, but within about 50m of its projected location. Underground drilling and mining have partly proven the interpreted extent plus some extra structures which were beyond detection by the HRS method.

Many of the features are described below and illustrated in the figures. Some of the features are of questionable significance, but are included to illustrate the minor anomalies a geologist must consider in an attempt to provide some warning of potential structures. As experience is accumulated, it should be possible to better differentiate between real and spurious seismic anomalies in the small fault category. In the meantime, it is safer to critically investigate any small anomaly with the extra data available from advancing faces rather than ignore them.

Feature 2

Interpreted from the 1987 survey as an area of deteriorated record with an obvious displacement of 5m down to the east, confidence low to medium. In retrospect, a minor anomaly is notable in the 1986 record but was too small for prediction at the time. During longwall preparation, methane drainage holes intersected stone and a fault of 4m throw was intersected by mining as shown on Figure 1. The fault is of short stike length. It is represented on lines MM and MN as clear breaks in the record, but on line NN which is closest to the mine intersection, there is no sign of a disturbance.

Feature 3

Interpreted from the 1987 survey as record deterioration at the ends of lines. A displacement of up to 8m was assigned with low confidence because of the loss of fold at the ends of the lines. Similar structures were not observed on an adjacent 1986 line. The seismic record shows an apparent thickening of the seam floor. No structure was intersected by methane drainage holes or by workings.

Feature 4

Good quality 1987 record indicated a medium confidence 15m fault on a single offset line with a similar character to the main fault. No sign of disturbance was noted on adjacent good quality lines. The feature was probably introduced by overprocessing.

Feature 5

Interpreted from good quality 1987 data on an offset line as a medium confidence fault with less than 10m throw. It correlated with displacements on an adjacent poorer quality 1986 line. The Manager Appin reports the area was drilled for methane drainage for Longwall 18 and no structure was intersected. It is probably a processing artifact.

Feature 6

Interpreted from good quality data on a 1987 offset line as a high confidence 21m throw fault of short strike length. There was no sign of it on adjacent high quality lines, but its character was assuring. It was located on the projection of the main fault and therefore interpreted as a continuation. It has been disproven by mining. It is a processing artifact.

Feature 7

Located on the end of a 1987 offset line with loss of fold, it was interpreted as a medium confidence fault with 8m throw. It aligned with the projection of the main fault. Mine workings have extended beyond this structure and disproved it.

Feature 8

Located to the east of the main fault, it was interpreted as an area of deteriorated record with a possible low confidence small fault associated with correlatable distinctive zones of poor record on lines MM and MN. As Brennan 19 Panel has traversed this area, the fault is not considered to exist.

Feature 9

Interpreted as a zone of deteriorated data from the 1986 and 1987 surveys and as it correlated with faulting in an adjacent bore, it was interpreted as a low confidence fault. Its character on line AA is that of a small trough. A medium confidence structure of up to 6m throw was interpreted on line 86P in the immediate vicinity. A fault has been intersected in Brennan 20 Panel in the vicinity (Figure 1).

Feature 10

This was interpreted as an area of complex faulting from the 1987 survey and was further investigated and clarified by the 1988 3D survey (Hatherly and Poole, this volume).

Feature 13

Interpreted as a high confidence fault of 12m on offset line 87HI. It was initially thought to have no correlatable features on adjacent lines, but similar minor low confidence structures can be noted on lines 87HI and 87II. It correlates with faulting intersected by 19 Maingate Panel. A fault of about 6m throw in A heading of the panel is immediately adjacent to the seismic line, but has no signature on the line.

CONCLUSIONS

Prior to the use of seismic, mine planning had to rely on borehole data only. At spacings of 1 km, borehole interpolation leaves much structural interpretation to the imagination. Seismic provides a cost effective means of interpolating between boreholes. However, it is a remote sensing tool and lacks the precision of the physical measurement of boreholes. Seismic anomalies critical to mine planning should be confirmed by boreholes, or mining.

High resolution seismic is not a panacea. It is another tool in the geologist's armoury which, if applied effectively can help to provide a much clearer picture of what lies ahead of the mine face and can assist mine planning to avoid costly mistakes.

Interpretation of data is an art rather than a science. The confidence assigned to interpretations is expected to improve with developments in data gathering and processing technology and with dedication of geologists' time to interpretation and reinterpretation as new evidence becomes available from mining and experience increases.

ACKNOWLEDGEMENTS

The authors wish to acknowledge to continuing support of the Collieries Division of BHP Steel International Group and their permission to publish this paper.

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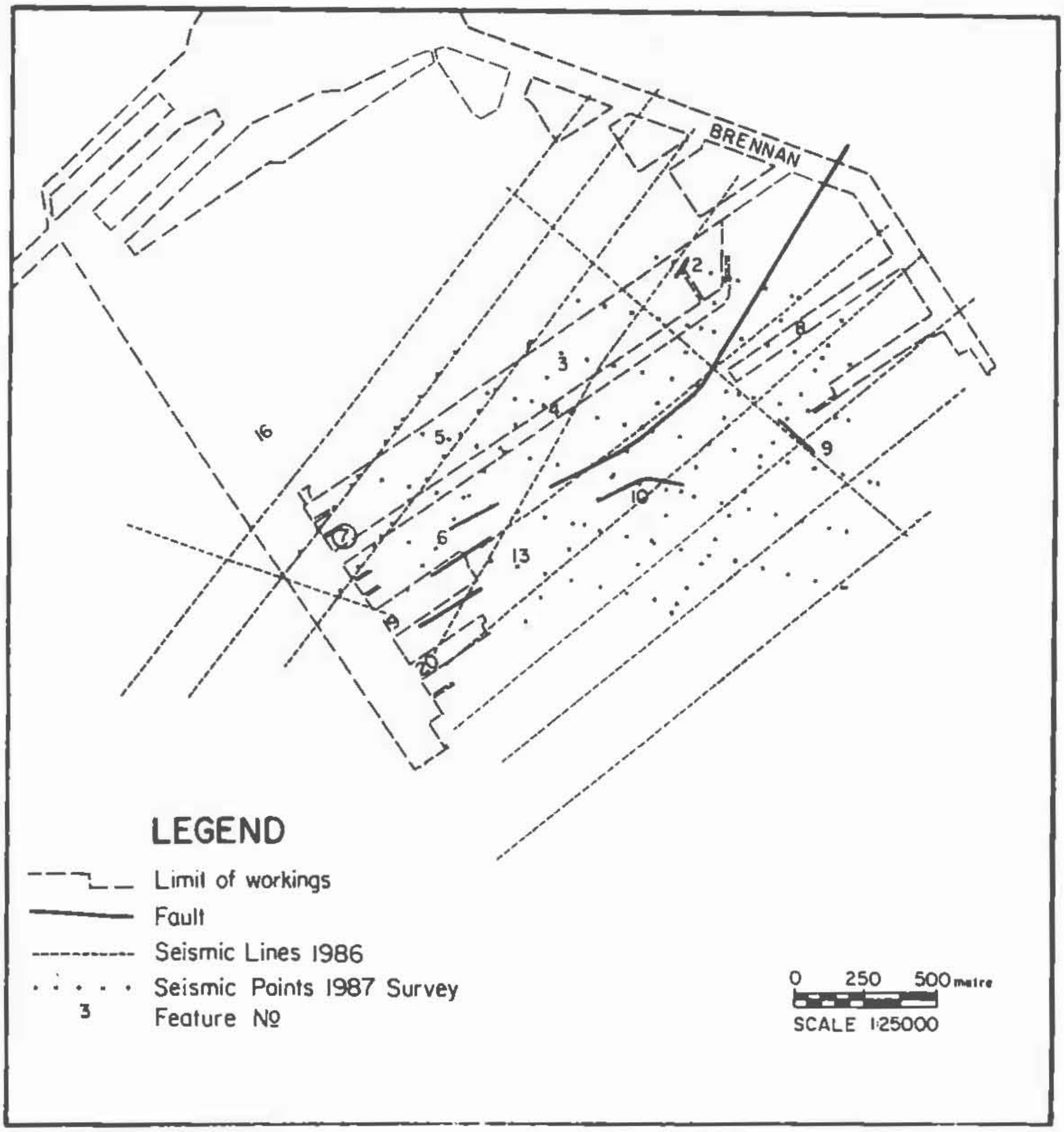
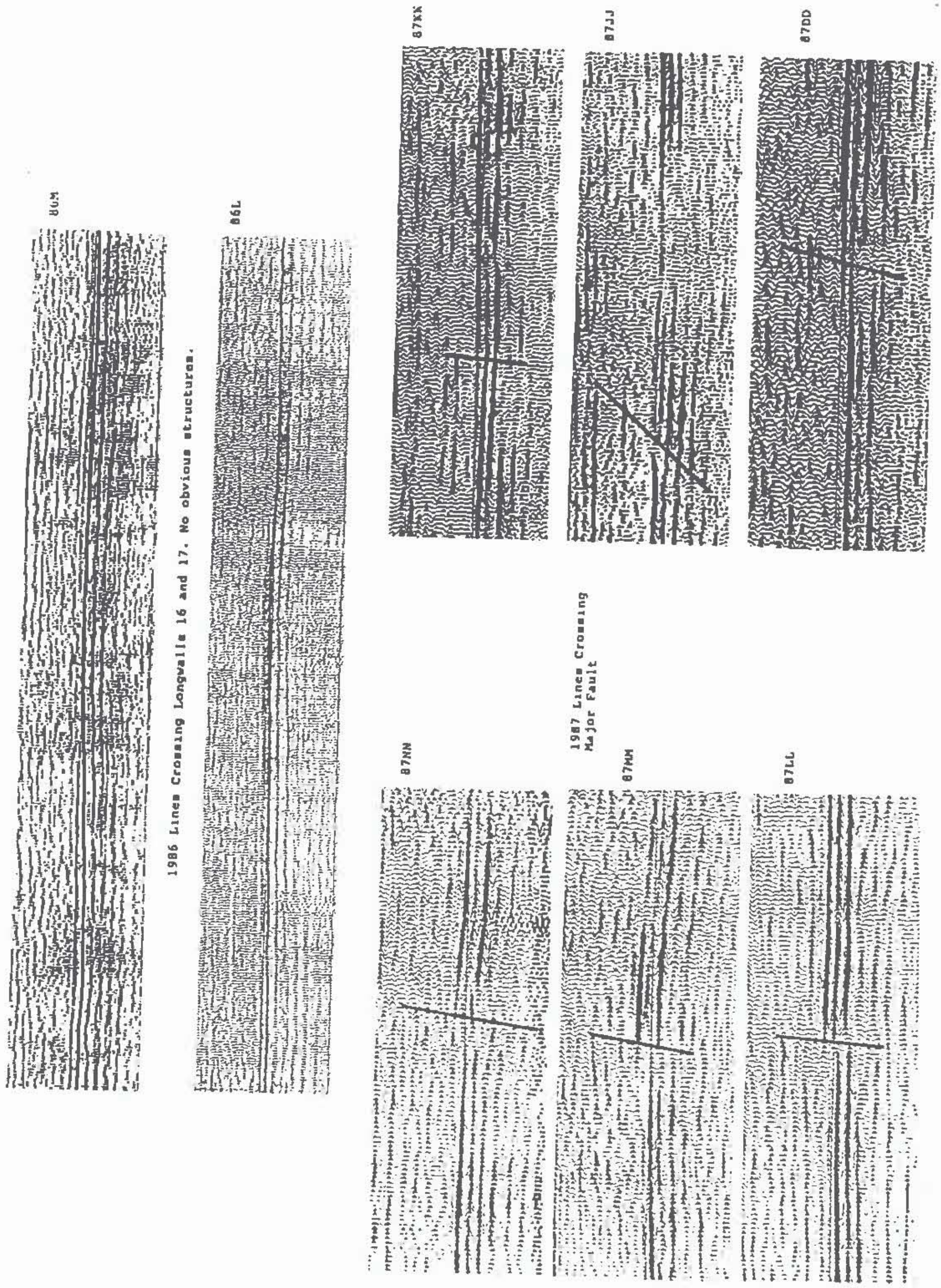


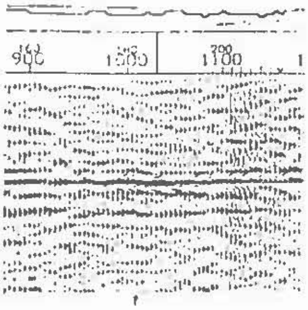
Figure 1.

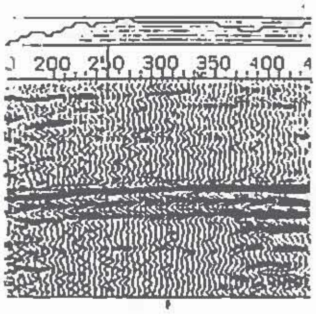


1986 Lines Crossing Longwalls 16 and 17. No obvious structures.

1987 Lines Crossing Major Fault

HIGH RESOLUTION SEISMIC


Feature 2 86P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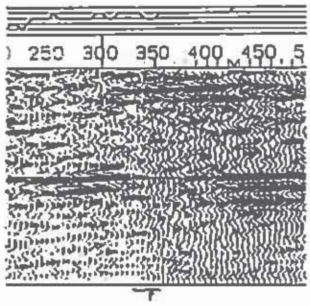
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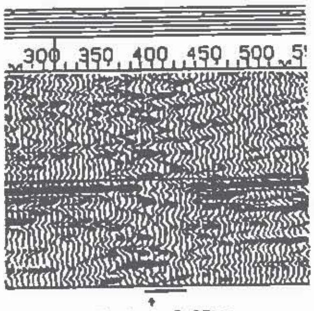
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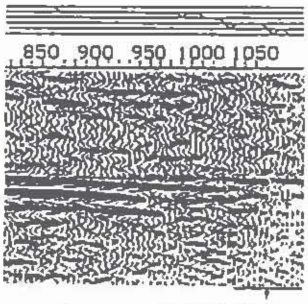
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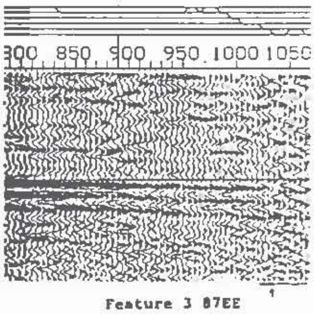
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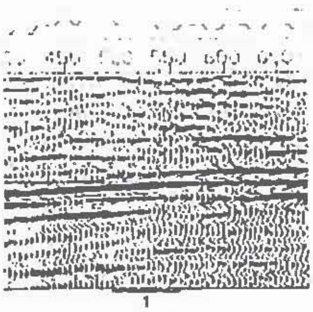
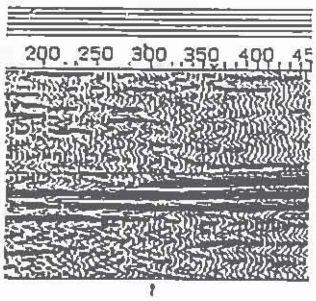

Feature 4 87JK


Feature 5 87IJ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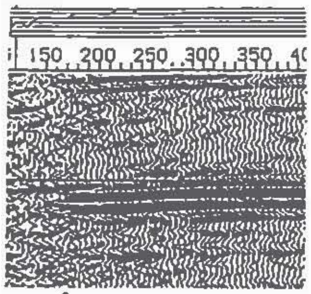

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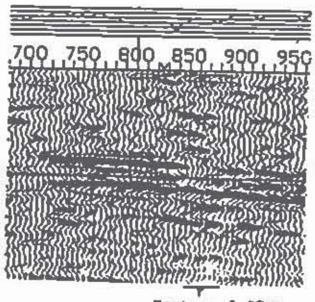
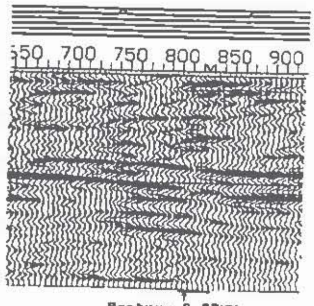
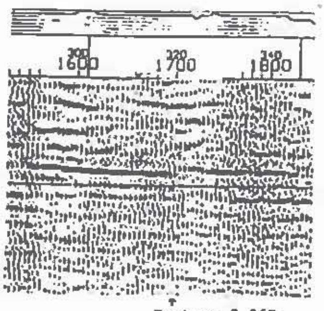


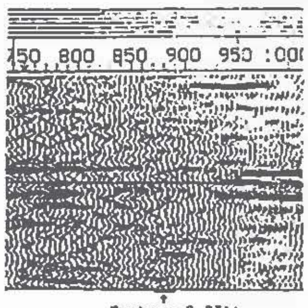
Feature 8 87MM



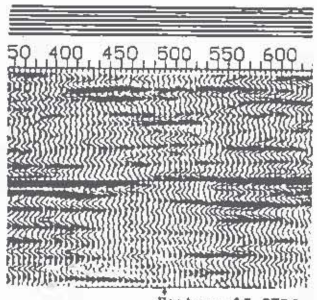
Feature 8 87MN



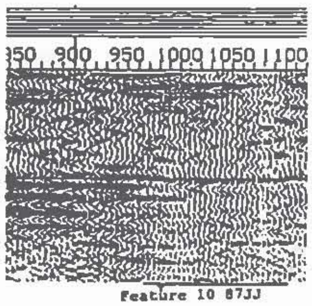
Feature 9 86P



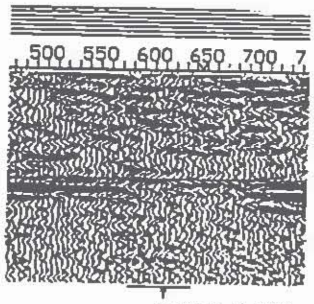
Feature 9 87AA



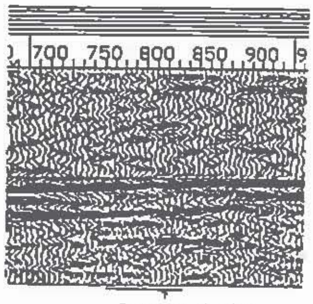
Feature 10 87BC



Feature 10 87JJ



Feature 13 87HI



Feature 13 87II

MARINE INFLUENCE ON COAL SEAMS

C.F.K. DIESSEL
University of Newcastle

Introduction

At the Twenty Second Newcastle Symposium some of the results of a lithofacies study of the Upper Carboniferous coal measures of the Ruhr Basin in Germany were presented (Diessel, 1988), which showed the distribution of a large number of subaqueous and marine sediments in a composite section covering 2660m of coal bearing strata including some 160 coal seam. Subsequent petrographic analyses of the coals have demonstrated their fluorescence intensities to be sensitive to the effects of marine influence, which will be the subject of this paper.

Some Chemical and Mineralogical Indicators of Marine Influence on Coal

Because the elemental composition of coal and its ash is one of the quality parameters frequently determined in routine analyses for a variety of practical purposes, it was the generally high concentration of sulphur in coals with marine roof sediments that was first noted to be of palaeoenvironmental significance (Mackowsky, 1943; Stach, 1949; Edwards and Baker, 1951; Petrascheck, 1952; Brooks, 1954; Teichmüller, 1955; Balme, 1956; Degens, 1958; Suggate, 1959; Diessel, 1961; Bailey, 1981; Warbrooke, 1981, 1987; and others). Subsequent studies by Ernst et al. (1958, 1960), Keith and Degens (1959), Potter et al. (1963), Eager and Spears (1966) on the distribution of boron and other trace elements in coal and clay minerals extended further the scope of identifying marine influence on coal and fossil-free sediments. It is not surprising therefore that much of the geochemical interest in the elemental composition of coal has been directed towards the identification of palaeosalinity indicators.

Most investigators of sulphur in coal (e. g. Goldhaber and Kaplan, 1974; Casagrande et al., 1977; Harris et al., 1981; Smith and Batts, 1984; Shimoyama, 1984; Cohen et al. , 1984; Casagrande, 1987; and others) derived lipids are added to the humic degradation products by Clostridium, an anaerobic bacterium which, according to Belyaev (1981), converts cellulose into fatty acids. Because these bacteria share the same environment and are often associated with the sulphate-reducing bacteria Desulphovibrio desulfuricans and Clostridium desulfuricans (Degens, 1965), syngenetic pyrite is often found in coalified cell tissue (Given and Miller, 1985). The resulting coal shows low tissue preservation and a high proportion of detrovitrinite, commonly with some relative enrichment of the more hardy components, such as detrital inertinite fragments, and/or liptinite. The latter is quite resistant in acid mires, but will decompose under neutral to slightly alkaline conditions. This leads to the formation of dispersed liptodetrinite, which occurs as submicroscopic impregnations in humic compounds, often too fine to be resolved by the optical microscope, although they have been readily identified in TEM (transmission electron microscope) studies by Taylor and Liu (1987; 1989).

On a molecular scale, the incorporation of bacterial lipids and absorbed and otherwise finely dispersed liptinitic material into the variously humified precursors of vitrinite increases the ratio between interstitial (intermicellar) material with low aromaticity and the condensed aromatic clusters (micelles). The result is enhanced development of a mobile phase during physico-chemical coalification, and a lowering of the rate of cross-linking and condensation of the aromatic framework. In terms of optical properties the consequences are a reduction in reflectance and an increase in fluorescence intensity of practically all coalified humic degradation products.

Figure 1 has been constructed from the results of vitrinite fluorescence intensity measurements carried out on a comprehensive set of Carboniferous Ruhr coals whose palaeoenvironmental setting had been assessed as part of the lithofacies study referred to above. The distribution curve of Figure 1A refers to normal humic coals without any noticeable marine or other unusual influence.

The distribution in Figure 1B has been obtained from coals which carry a lacustrine to brackish roof. Identification of these conditions was based on the occurrence of the respective fossils in the roof sediments, mainly bivalves, worm burrows and feeding traces (e. g. Planolites ophtalmoides). In the lower coalification range the position of many data points obtained from coals with strong bioturbation in the roof is well above the normal distribution curve in Figure 1A, whereas most of the seams with freshwater bivalves in the roof plot more closely to the latter. In the upper coalification range all values converge with the normal distribution.

Figure 1C gives the fluorescence intensity values for the marine influenced coals. They all represent well known marine horizons in the European Carboniferous System including Aegir, Domina (L Seam), Katharina, Wasserfall, Plasshofsbank, Girondelle and Wasserbank. Because they do not contain low rank examples, two samples from the Greta Seam from the Sydney Basin have been added. This seam is strongly marine influenced and carries a brachiopodal fauna in its roof. The lower rank coals display considerably higher fluorescence intensities than the normal coals, and several samples plot also above the brackish influenced coals.

In order to highlight differences between the three palaeoenvironmental settings, normalised residuals of the measured fluorescence intensities are illustrated in Figure 1D to F. The use of normalised residuals has the advantage that they are independent of actual fluorescence values and thus allow comparison between different instruments and methods of intensity determinations. In all three diagrams the zero line represents the regression curve for ordinary humic coals displayed in Figure 1A, whereas the bars extending into the positive and negative regions above and below zero indicate the deviation in percent of the measured values from the fitted values in accordance with the regression equations indicated in Figure 1A to C . In Figure 1D the positive and negative variations are more or less in balance, although some very low values occur in the lower rank range. They have been measured in stratigraphically high Westphalian C coals which are situated not far below the Late Carboniferous unconformity and have been affected by Permian weathering. Diagrams E and F of Figure 1 display strong positive trends of the residuals, particularly the marine influenced coals. Negative deviations occur in some high rank marine influenced coals, but they are likewise artefacts due to oxidation, having been sampled in defunct open cuts.

The results are interesting not only because they add fluorescence microscopy to the arsenal of useful tools in palaeoenvironmental analysis, but, considering that marine influenced coals are also known to report extremely high fluidities during carbonisation, they also re-affirm the positive correlation between fluorescence intensity and coking properties.

Acknowledgements

The author wishes to thank Dr. W. Pfisterer of Ruhrkohle AG for the loan of the set of coal samples used in this study.

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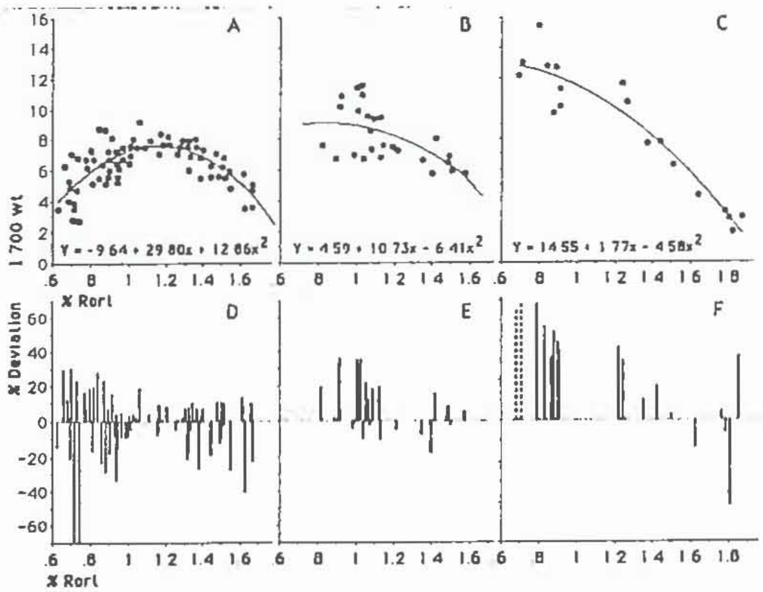

Figure 1. Mean fluorescence intensities measured on telovitrinite in three sets of Carboniferous coals from the Ruhr Basin in water immersion at a wavelength of 700 nm. A = normal humic coals formed on alluvial and upper delta plains; B = coals with freshwater lacustrine to brackish roof sediments; C = coals with marine roof sediments; D to F = residuals as normalised deviation (in %) from fitted curve in A. The two dashed bars in F and the corresponding data points in C refer to the Greta Seam in the Sydney Basin of New South Wales. After Diessel (in prep.).

GERMAN CREEK FORMATION & MORANBAH COAL MEASURES : A TRANSITION FROM MARINE SHELF TO UPPER DELTA PLAIN

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INTRODUCTION

This paper describes and interprets the sedimentology of the Late Permian German Creek Formation and compares it to the Moranbah Coal Measures, a laterally equivalent unit to the north. Both units support extensive coal mining operations in the Bowen Basin. The work presented here forms part of a project based at the University of Queensland and funded by BP Petroleum Development Ltd (London) that aims to provide a detailed database on facies geometry within alluvial and fluvio-deltaic coal-bearing sequences of the Bowen Basin (Falkner and Fielding, 1989).

STRATIGRAPHY

The units of interest here form part of the fill of the Bowen Basin in eastern Queensland (Fig. 1). The Bowen Basin has been interpreted as a foreland basin, associated with convergent margin tectonics at the eastern edge of the Gondwana continent (Murray, 1985). The fill is of Permian to Triassic age, with a dominantly marine Early Permian section overlain by a mainly coastal plain to alluvial plain (coal-bearing) Late Permian sequence, and a terrestrial Triassic interval.

The early Late Permian German Creek Formation crops out in an arcuate belt from Emerald in the south to Saraji in the north, and supports the Gregory, Oaky Creek, German Creek and Norwich Park mines (Fig. 1). This unit can be divided into a lower 160 m thick unit barren of coal and an upper 110 m thick coal-bearing interval. The Formation is enclosed above and below by sequences of marine shelf origin, the Macmillan and Maria Formations respectively (Fig. 1). The laterally equivalent Crocker Formation to the south and east (Fig. 1) is a nearshore marine shelf deposit, while the terrestrial Moranbah Coal Measures to the north are laterally equivalent to the upper German Creek Formation. Coal seams are traceable continuously between the upper German Creek Formation and the Moranbah Coal Measures.

The Lilyvale-German Creek-Dysart-Goonyella Lower seam (terminology from south to north and extending into the Moranbah Coal Measures) constitutes the major economic seam of the German Creek Formation. It has upper and lower splits and is on average 3.0 m thick, low in ash and sulphur and is exported as coking coal. The other seams in the unit are in stratigraphic order the Corvus, Tieri, Aquila and Pleiades seams which also split and are generally thinner and higher in ash and sulphur than the German Creek seam.

DESCRIPTION AND INTERPRETATION

The German Creek Formation is sandstone-dominated with subordinate thin, fine-grained sequences of interbedded siltstone and sandstone. Depositional models for the unit have been proposed by Phillips *et al.* (1985), Godfrey (1985) and Mallett *et al.* (1987) who postulated a delta plain to marginal marine setting. The notion of a coastal environment of deposition is supported by the unit's stratigraphic setting, surrounded conformably by sequences interpreted as marine shelf in origin. The lower German Creek Formation contains an abundant marine fauna and is extensively bioturbated. Coal seams in the upper part of the Formation can be traced continuously over hundreds of kilometres indicating that the coastal plain was areally extensive. The upper part of the German Creek Formation can be divided into five separate facies; A, B, C, D and E. Facies A, B and C occur only in the interval between the German Creek and Corvus seams. Intervals between overlying seams are dominated by facies D whilst the seams themselves are designated facies E.

Facies A, Distributary Channel

This facies comprises erosively based fine to coarse-grained quartz-lithic sandstone bodies that vary from 2 to 10 m thick with an average of about 7 m (Fig. 2). There is a degree of variability in the nature of this facies at the four mines at which it is exposed. Cross-bedding and ripple cross-lamination are ubiquitous with unimodal or bimodal palaeocurrent directions parallel to the direction of elongation of the body (Fig. 3). However, lateral accretion although common is not always present. Units displaying bimodal directions are less laterally extensive and may contain combined flow ripples. Bioturbation is rare to common. Sandstones with unimodal flows often display a rhythmic interlamination of thin siltstones. Facies A occurs only in the interval between the German Creek and Corvus seams which is approximately 30 m thick and is intimately associated with Facies B.

Facies A is interpreted as the active fills of distributary channels affected by tidal flows on a lower delta plain.

Facies B, Interdistributary Bay

Units 1 to 10 m thick of siltstones interbedded with fine to coarse-grained sandstones which can be traced for tens of kilometres characterise this facies (Fig. 2). They show sharp or gradational boundaries with adjacent facies and display flat or ripple cross-lamination with evidence of both current and wave activity. Small-scale cross-bedding associated with thicker, sharply bounded sandstone beds and ripple cross-lamination show bi- or polymodal palaeocurrents (Fig. 3).

Units of Facies B are closely associated with Facies A and are thought to represent accumulation in relatively tranquil conditions within interdistributary bays by overbank and crevasse splay deposition.

Facies C, Barrier Spit

Facies C comprises hard, medium-grained quartz-sandstone bodies 1 to 6 m thick that internally show flat and very low-angle lamination and rare pebbles. These units are not laterally extensive and appear to be elongate parallel to palaeoshore lines. They do not contain any sedimentary or biogenic structures and are associated with facies A and B.

This facies is interpreted as a barrier spit deposit formed by wave reworking of channel mouth sands.

Facies D, Proximal Mouth Bars

Sandstone bodies of this facies vary from 4 to 20 m thick and are approximately 10 by 50 km in plan, elongate perpendicular to palaeocurrent direction. These medium to coarse-grained quartzose sandstones have sharp, planar, sulphur stained bases and show thick tabular bedding. Internally they display flat, low-angle and undulating lamination and hummocky cross-stratification (Fig. 2). Cross-bedding and ripple cross-lamination are rare while wave ripples are common. Bioturbation is abundant, commonly as deep, vertical, tubular burrows. Rare marine bivalves are present. Sandstones bodies of Facies D are interpreted as proximal mouth bars of shallow water marine deltas, constructed under the influence of fluvial outflow, waves and tides.

Facies E, Peat Mires

The upper German Creek Formation contains five coal seams that can be traced continuously for hundreds of kilometres, they are in stratigraphic order the German Creek, Corvus, Tieri, Aquila and Pleiades seams. These split and coalesce, vary from 0.3 to 5 m in thickness, are bright, low ash and are low to moderate sulphur.

Facies D represents accumulation in long-lived, low-lying, areally extensive peat mires that were remote from clastic sediment input and only rarely received flood-borne sediment or distal, airfall volcanic ash.

SYNTHESIS

Lateral accretion, facies maps and the variability of palaeoflow azimuths in some exposures suggests that most distributary channels were moderately sinuous. Bipolar palaeoflow directions indicate current reversal due to tidal flux, while unimodal palaeocurrents in similar units may be due to substantial fluvial outflow ensuring that bedforms were aligned in the downstream direction. Rhythmic interbedding in these latter channel fills implies a regular alternation of high and low energy possibly caused by tides affecting outflow velocities. Detailed facies mapping also shows channel bifurcation at the distributary mouth.

Interdistributary bay deposits (Facies B) are mostly fine-grained, interpreted as representing overbank deposition from adjacent channels, minor crevasse splay deposition, and also suspension fallout in tranquil bay and tidal flat environments.

Horizontally laminated quartz-sandstones are interpreted here as barrier-spit deposits that resulted from wave reworking of channel sands adjacent to channel mouths.

The mouth-bar deposits identified in this study are sharply based and show no evidence of a coarsening-upward progradational character (Fig. 2). These are interpreted as proximal deposits close to the sites of river mouths, indeed the distributary mouth of two channels has been mapped from the distribution of Facies A and B at Gregory Mine (Fig. 3A). The mouth bar sands are dominated by wave and/or combined flow structures, indicating a major influence of wind-driven waves in the marine environment.

Facies E, peat mire deposits are somewhat enigmatic in their enormous lateral extent, at least along strike (north-south). In the east-west direction seams tend to thin, split and contain higher ash levels as they are traced eastwards into the subsurface. This trend coincides with a change in clastic facies from the assemblage described above to a more marine-dominated character.

SUMMARY

The presence of a marine fauna, hummocky cross-stratification, bipolar palaeoflow directions and extensive bioturbation indicate that the lower German Creek Formation accumulated in a shallow marine shelf to lower delta-plain environment.

The overall environment of deposition of the upper German Creek Formation is interpreted to be lower delta plain of a mixed influence (i.e. wave-tide-fluvial influenced) delta system which prograded eastward into the marine Bowen Basin. The situation envisaged for the German Creek Formation is similar to that displayed by the modern Burdekin River delta on the east coast of Queensland (Coleman and Wright, 1975). Very few published descriptions of ancient, mixed-influence deltaic systems exist, which negates detailed comparison with other sequences.

Major distributary channels were probably of moderate sinuosity, and dominated by fluvial outflow. These issued into the marine environment to the east, where the marine shelf was affected profoundly by wave activity, leading to the reworking of channel-borne sediment into tabular-shaped mouth-bar deposits. In between the major channels were minor channels which acted as tidal inlets and were strongly influenced by the action of tides, and interdistributary bay/tidal flat deposits. Peat mires were periodically established on the abandonment surfaces within the lower delta plain. The great lateral extent of coal bodies is rather difficult to explain in terms of purely sedimentary processes (particularly in a lower delta plain setting) and may imply the influence of external base level changes.

In contrast the laterally equivalent Moranbah Coal Measures display features that suggest it accumulated in an upper delta-plain environment. Ongoing facies analysis reveals extensive channel systems from 5 to 70 m thick with unimodal palaeoflow directions to the SW, S, SE and E. Channels are of several different types and commonly show lateral accretion. Fine-grained overbank facies show bimodal palaeocurrent directions, rare bioturbation and wave ripples. These features and a lateral transition with sediments of lower delta-plain origin indicate that the Moranbah Coal Measures accumulated on an upper delta-plain.

The sequence comprising the lower German Creek Formation, upper German Creek Formation, and Moranbah Coal Measures represents a transition from a shallow marine shelf, to mixed-influence lower delta-plain, to upper delta-plain respectively. The superb exposure of this sequence reveals the three-dimensional geometry of component sediment bodies and enables palaeoenvironmental reconstruction on a regional scale.

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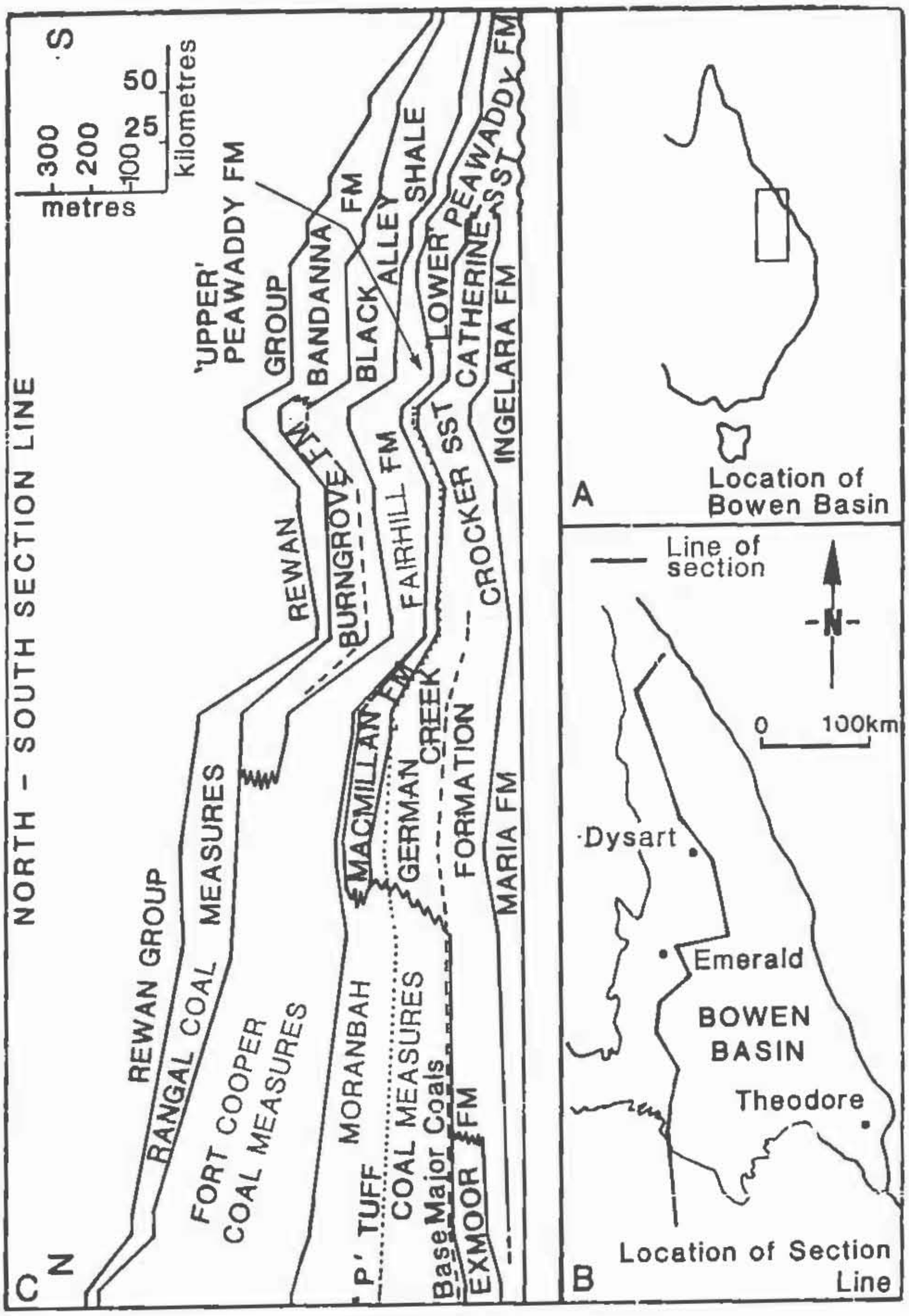

Fig. 1. North-south cross-section of the middle to late Permian succession of the Bowen Basin (modified after Draper and Balfe, 1985).

MIXED-INFLUENCE DELTAIC SEQUENCE

Fig. 2. Lithological logs of sequences exposed at A) Gregory mine illustrating Facies A (Distributary channel), B (Interdistributary bay), C (Barrier Spit) and E (Peat mire), and B) Oaky Creek mine illustrating Facies D (Proximal mouth bar).

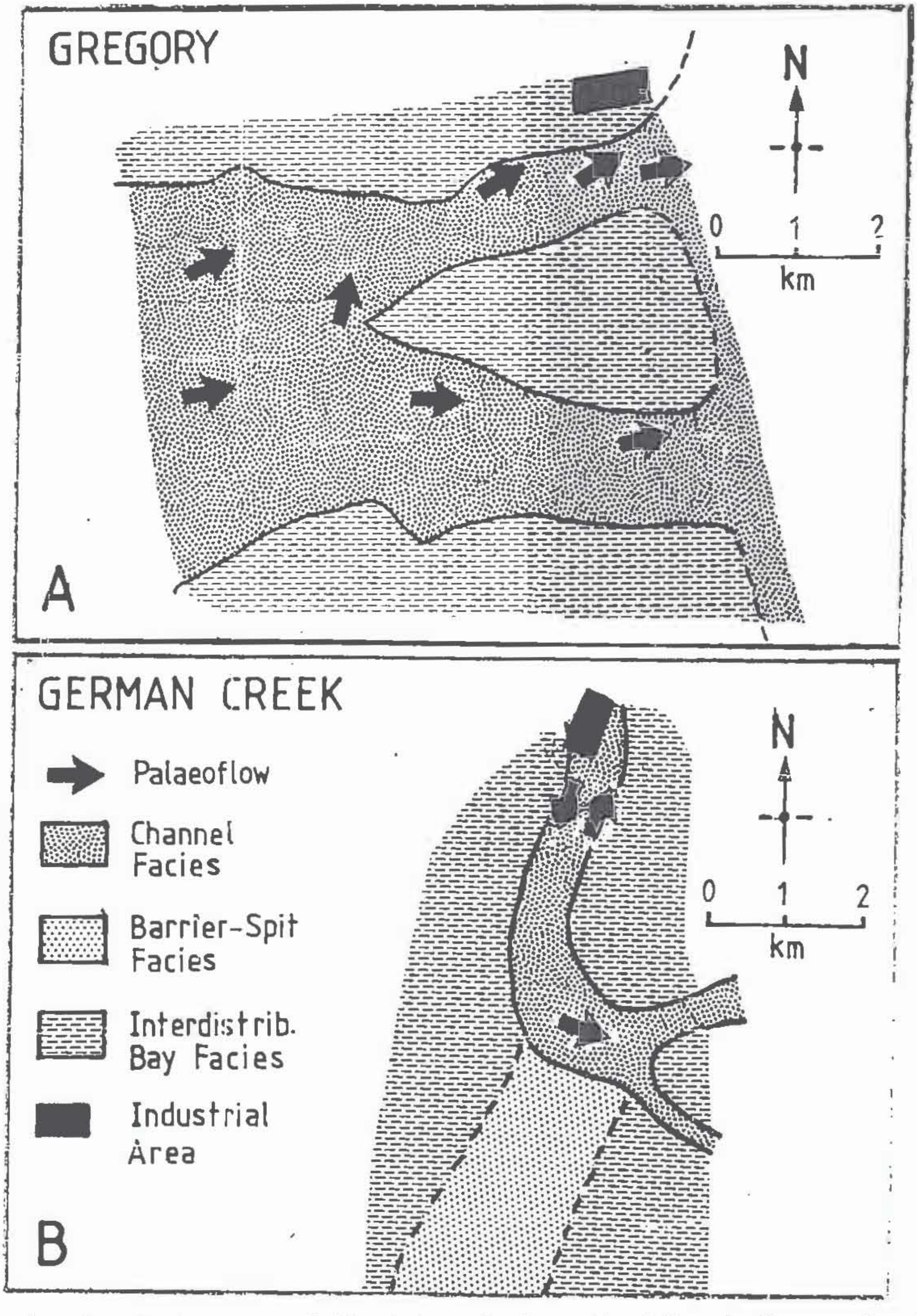

Fig. 3. Facies maps of the interval above the Lilyvale/German Creek seam at A) Gregory mine and B) German Creek mine.

ASPECTS OF THE LOWER PERMIAN SEQUENCES IN THE MANNING RIVER AREA AND THEIR TECTONIC SIGNIFICANCE

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INTRODUCTION

Sediments of the Manning Group [Voisey, 1958], located between 151°40' and 152°20'E, and 31°30' and 31°55'S, in the southern New England Fold Belt, form part of a broadly distributed suite of marine clastics, of Lower Permian age [figure 1]. These sequences occur in a discrete tectonic episode which began after Palaeozoic subduction [Cawood and Leitch, 1985] culminated in the Late Carboniferous, andean style volcanism of the Currabubula arc [McPhie, 1987], and ended with the Late Permian Hunter-Bowen Orogeny [Collins, this volume]. To the south, in the northen Sydney Basin, this time interval is represented by the Dalwood Group, Greta Coal Measures and Maitland Group sediments [McClung, 1980].

Previous authors [eg. Roberts and Engel, 1987; Glen and Beckett, 1989] have called upon tectonic events occurring in the New England Fold Belt since the earliest Permian to assist in interpreting events in the Sydney Basin. If, however, this is to be successful, then a common provenance and a sense of relative position between the Sydney Basin and the New England Fold Belt needs to be established [cf. Jones et al., 1983].

It is probable that the Lower Permian Boggabri [McPhie, 1984], Gunnedah [Hill, 1986], Werrie [Flood et al., 1988], Gyrran [Summerhayes, 1982] and Alum Mountain Volcanics [Roberts and Engel, 1987] [figure 1] are of equivalent age, although this has yet to be established. This establishes a terrane link between the Sydney Basin and the less deformed portion of the New England Fold Belt [the Tamworth Synclinorial Zone or Zone A of Leitch, 1974] [figure 1]. Terrane linkage, by common volcanic provenance, between Zone A and the more highly deformed Zone B [Leitch, 1974] of the New England Fold Belt has been indicated for the Late Devonian / Early Carboniferous by Cawood [1982], however, see Aitchison [1988] for a more detailed assessment. Allan and Leitch [in press] have shown that characteristic Lower Permian sequences exist on either side of the Peel Fault Zone, which separates Zones A and B, thus establishing a linkage at this time.

It should be noted, however, that the linking events discussed are of a regional character, extending over 100's of km and do not indicate the relative positions of the smaller terranes, or blocks, during the Early Permian. Final terrane linkage occurred in the New England Fold Belt prior to pluton stitching in the Late Permian and Early Triassic [Flood and Aitchison, 1988].

That dispersal has occurred is indicated, for example, by the displacement and reversal of facing direction of the Hastings Block [Lennox and Roberts, 1988] and the dispersed nature of the Woolomin Group sediments. The dispersal must have taken place around Mid-Late Permian times [cf. Collins, this volume; Cawood and Leitch, 1985], and hence may have been initiated by tectonic events in the Early Permian.

The purpose of this paper is to discuss the Lower Permian sequences in the southern New England Fold Belt, and to suggest a tectonic setting for them.

MANNING GROUP SEQUENCES

Sediments of the Manning Group are of Lower Permian age. 'Allandale' faunas are present in the Upper Barnard River area [Allan and Leitch, in press] and Fauna II fossils have been recorded by Mayer [1972], and Engel and Laurie [1978].

The sediments of the Manning Group are flanked by the Mid? Devonian [Aitchison, 1988] Woolomin and Sandon Associations to the north and west and by the Early Devonian to Carboniferous Tamworth Group, Parry Group and Bowman Beds to the south and east [Gilligan and Brownlow, 1987]. In most places the contacts appear to be faulted, but Allan and Leitch [in press] have established that the sediments unconformably overlie the Woolomin Association in the Upper Barnard River area and that a similar relationship exists in the Hastings River Region, 14 km. NW of Comboyne. Mayer [1972] also noted a possible unconformity between the Manning Group and the Woolomin Association [then Myra Beds] at one location, but was unable to confirm it due to poor outcrop.

Mayer [1972], made the following informal subdivisions of the Manning Group, using only reconnaisance mapping. The Wards Creek unit at the base, which comprises 600+ m of thick bedded or massive breccia and rare sandstone is conformably overlain by the Giro diamictite, which is up to 6,150m thick. The latter is overlain by 850m of pebble conglomerate, less abundant diamictite and minor limestone called the Glory Vale Conglomerate and then by 900+ m of the Colraine Mudstone consisting of black siltstone, less common sandstone and rare limestone. It is succeeded by the Kywong Formation, at least 1,600m of conglomerate, sandstone, siltstone and associated ash-fall tuff and "andesitic" lava flows. A total thickness of 9,000+ m was thus assumed.

LOWER PERMIAN TECTONICS

These broad subdivisions do not stand up well to detailed field inspection. For instance, diamictites from the Glory Vale Conglomerate are indistinguishable in hand specimen and clast component from the Giro diamictites. Further, sequence reversals were mapped [Mayer, 1972] without any indication of overturning. It is probable that some repetition has occurred due to thrusting. A rough estimate, based on Mayer's interpreted faults, indicates overthrusting from the northeast, with a displacement of about 6 km [using a 'bow-and-string' estimate; McLennan, 1989]. Reverse faulting consistent with this hypothesis has been noted in diamictites of the Glory Vale Conglomerate. Further, because of the massive nature of the diamictites [pebbly siltstones and mudstones], it has not yet been possible to establish whether the measured thickness is actually a stratigraphic thickness, or whether a facies thickness has been measured. Nevertheless, it is difficult to justify a basin thickness of 9km, within the restricted areal distribution of the Manning Group, unless a strike-slip setting is invoked [cf. Nilsen and McLaughlin, 1985]. More data needs to be collected, before a true basin thickness can be established.

The Manning Group stratigraphy records a transition from an initially terrestrial environment to deep marine in its early history, followed by shallow marine deposits in the later stages. The basal breccias, where present, consist of angular clasts derived exclusively from a proximal source. They are probably alluvial fan deposits. Mayer [1972] interpreted the Giro Diamictite and the Glory Vale Conglomerate as mass flow deposits, mainly within a deep marine setting. This is evidenced by graded sandstone/siltstone interbeds, and by sediment transport directions, initally from the northeast, and then towards the southeast, which is the apparent axis of the basin [Mayer, 1972], features typical of mass flow deposits. The Colraine Mudstone and Kywong Beds are shallower water, traction current deposits.

The clasts in the conglomerates and diamictites are derived either from the adjacent Woolomin Association, from contemporaneous silicic to intermediate volcanism [Mayer, 1972] or from a granitic source. The clasts are almost invariably well rounded and there is no evidence, such as clast faceting or striations, for a glacial origin. The matrix grains are generally angular [Mayer, 1972], indicating the immature nature of these sediments.

The granitic clasts are enigmatic. Leitch [1988] suggested that they may be derived from pre- or early Permian intrusive rocks in the region, such as the S-type Bundarra and Hillgrove suites [cf. Kleeman, 1988]. The clasts, however, appear to be I-types [W. J. Collins, pers. comm.] and do not resemble either of these suites [B. Landenberger, pers. comm.]. They may be derived from the Lachlan Fold Belt, or further afield, in which case glacial or fast-ice transport may be involved.

COMPARISONS WITH OTHER LOWER PERMIAN BASINS

The gross features described above are typical of other Lower Permian basins in the southern New England Fold Belt. Compositionally similar diamictites of mass flow origin are present in the Hastings Block [Lennox and Roberts, 1988]. Lower Permian sediments in the Apsley River area [152°01'E; 30°59'S] approximately 100km NE of the Manning Group sequences, rest unconformably on Woolomin-type sequences and consist of basal conglomerates and sedimentary breccia of proximal provenance, overlain by graded sandstones, diamictites and mudstones, and also contain exotic [?] granitic clasts. Similar mass flow deposits are present further N, at Halls Peak [Degeling and Runnegar, 1979; Leitch, 1982] although a basal section has not yet been located. Similar sequences are present at the Glenrock area [Offler, 1982] and in the Upper Barnard River area [Allan and Leitch, in press]. These sequences are along strike to the NW of the Manning Group, and represent a continuation of the Group. Mass flow deposits truncated by the Peel Fault on the western side of the New England Fold Belt appear to have developed under similar conditions [Brown, 1987].

TECTONIC SETTING

The presence of widely separated sequences, containing locally derived, upward fining, rapidly deposited sediments is typical of basins formed in extensional tectonic settings [Mitchell and Reading, 1986]. The considerable thicknesses of the mass flows [100's of m] is also typical of extensional basins, as opposed to mass flows in compressional basins [10's of m] [Shanmugam and Moiola, 1988].

Other factors, not discussed above, which contribute to this conclusion are the presence of coeval starved sequences [in this case oil shales] in the Lower Permian Temi Formation [Gilligan and Brownlow, 1987], primitive basalts from the western side of the New England Fold Belt developed on thinned continental crust [Flood et al., 1988] and mid ocean ridge or within plate basalts in the Nambucca Block [Asthana and Leitch, 1985; Leitch and Asthana, 1985].

The presence of an Andean type margin to the west of the New England Fold Belt in the Latest Carboniferous [McPhie, 1987] is conducive to the stepping out of the subduction zone [cf. Park, 1988 p96], placing the proto New England Fold Belt in a back arc setting. This is only one possible mechanism for generating extension during the Lower Permian. Others include the subduction of a spreading ridge, a process similar to the present situation in the western USA, a model suggested by Blake and Murchey [1988]. A strike-slip component during extension is favoured by Cawood and Leitch [1985]. Another possibility is the formation of a mantle diapir, unrelated to major plate interactions [cf. Park, 1988 p85].

Whatever the ultimate cause, extension and limited spreading was replaced by E-W compression by ca. the Late Permian and deposition of the characteristic Lower Permian sequences ceased.

IMPLICATIONS FOR THE SYDNEY BASIN

If the above arguments are valid, then by analogy, the early history of the Sydney Basin was probably dominated by extensional tectonics, until about Tomago Coal Measures time [Collins, this volume], after which sedimentation was controlled by compressional tectonics . This would then place the Sydney Basin in a foreland setting, as suggested by Glen and Beckett [1989].

ACKNOWLEDGEMENTS

I would like to thank my supervisors, Drs. Bill Collins and Robin Offler, for their persistence in generating this paper, and colleague Bill Landenberger for his help and discussions in the field.

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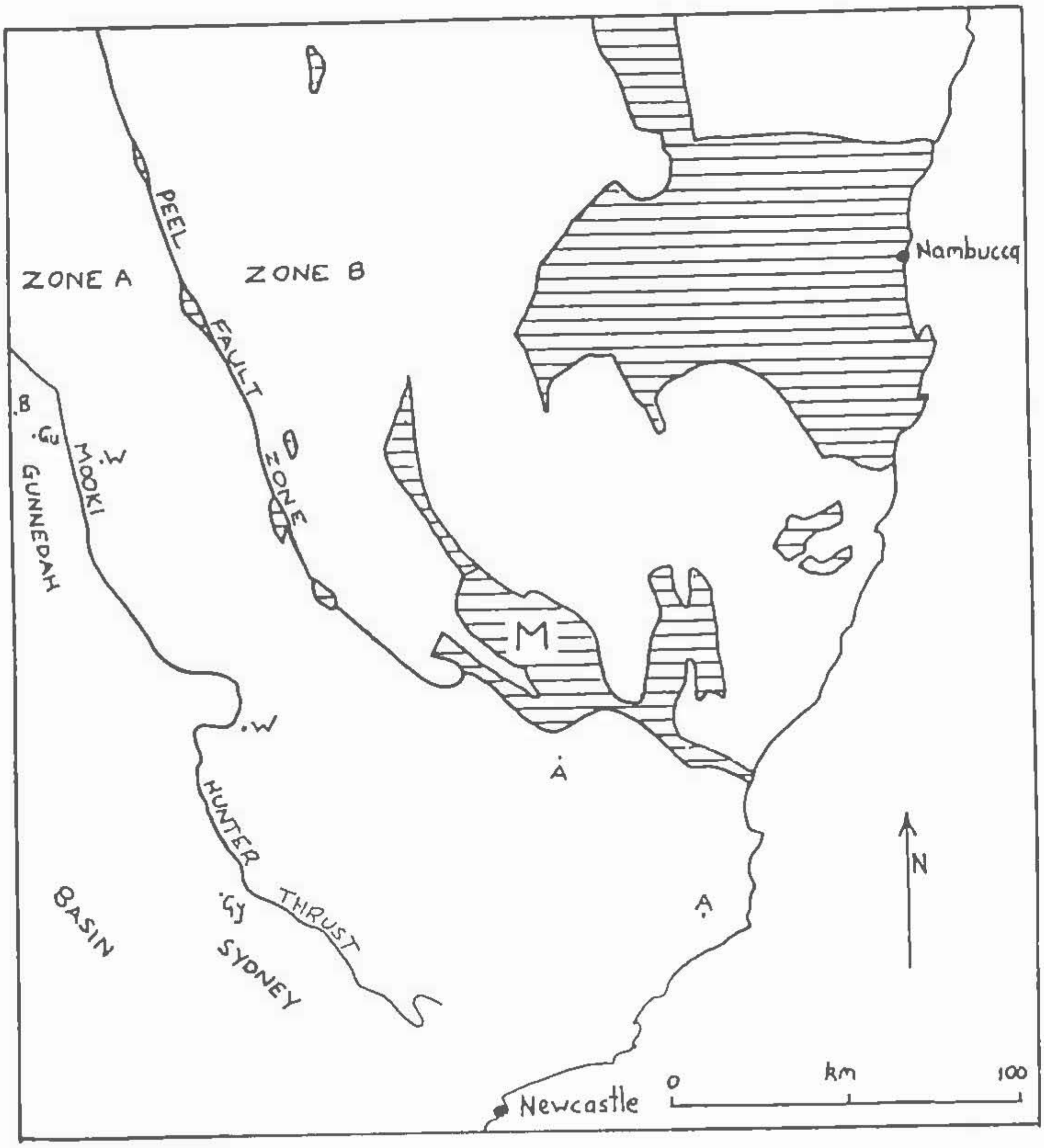

Figure 1. Manning Group sediments [M] and other Lower Permian marine clastics/diamictite associations in the southern New England Fold Belt [hatched] and volcanic centres [A= Alum Mountain; B=Boggabri; Gu=Gunnedah; Gy=Gyrran; W=Werrie] After Leitch, 1988.

PROGRESS IN THREE-DIMENSIONAL SEISMIC SURVEYING, APPIN AREA

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[2] BHP T & ES, Figtree

INTRODUCTION

In January 1988, ACIRL commenced a three year NERDDC funded research program aimed at developing and demonstrating the three-dimensional seismic reflection method for coal seam mapping. The method is routinely used in the petroleum industry to areally map a region of interest but it was untried in the Australian coalfields. Significant contributions are being made to the project by the NSW Department of Minerals and Energy (data acquisition), University College Australian Defence Force Academy (development of a high frequency seismic vibrator) and Curtin University (3D data processing and interpretation).

To date, 3D surveys have been conducted near Coober Pedy, at German Creek and Appin (two surveys). The results of the Coober Pedy and first Appin survey were reported to the 1989 Newcastle Symposium (Hatherly, Evans, Reich and Poole 1989). This paper presents new results from the second Appin and German Creek surveys and follows up on the results of the first Appin survey. Progress in the development of the high frequency vibrator is also described.

1988 APPIN 3D SURVEY

The results of the 1988 Appin survey are shown as a three-dimensional perspective in Figure 1. Two faults of opposite throw are evident, growing from zero displacement to some 20 m.

The area of the survey was chosen from previous high resolution seismic surveys as an area containing a complex scissoring of a major fault with a change in its strike. The 3D survey clarified this as two faults. In-seam seismic surveys and longhole drilling also confirm the presence of faulting.

P. HATHERLY (ACIRL Ltd) and G. POOLE (BHP Steel Division)

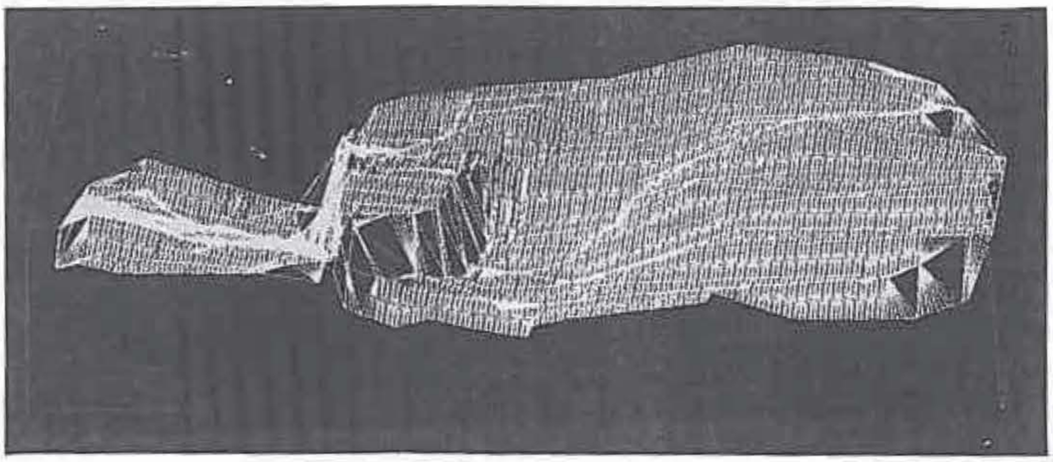

Figure 1. 1988 Appin survey result - 3D perspective of Bulli coal seam horizon

The original 2D seismic survey allowed for planning of longwall development, but one panel, driven close to the major faulting, intersected faults too small to be detected by surface seismic and had to be abandoned.

The area south of the main fault will be mined in 1990, giving further clarification of the 3D structure.

1989 GERMAN CREEK SURVEY

In August 1989, a 3D survey was conducted at the German Creek Mine in the Bowen Basin. This was the first seismic reflection survey at the mine since an unsuccessful high resolution seismic survey conducted by the National Coal Board in 1978. Exploration relies heavily on drilling.

The survey covered an area of 1152 m by 640 m and crossed an expected fault. There were 13 shot lines 640 m long, 72 m apart with shot holes at 20 m intervals drilled to a depth of about 12m. Perpendicular to these were three geophone lines spaced 160 m apart, each 1152 m long. The geophone interval was 6 m.

Initial processing of the data led to disappointing results. The reflectors were very weak and while some of the more 'creative' of the seismic processing options were applied to enhance these on individual lines, overall continuity across the survey area was poor.

Subsequent processing, however, appears to have produced a much better result. The main changes have been to recognise that:

1. The German Creek Seam (depth of about 200 m) is a weak reflector and that there are more prominant overlying coal reflectors. The processing was therefore concentrated on these.

2. Ground roll interferes significantly with the reflections. In 3D surveys, the ground roll from offset shots arrives along a curved trajectory and conventional velocity filters which remove linear events can't be applied. At German Creek, the ground roll interfered with the shallow reflection events on traces where the shot to geophone distance was less than 110 m. Traces for shots closer than 110 m to the geophones were therefore discarded.

3. Deconvolution had an undesirable effect. Deconvolution removes the cyclic components normally assumed to be due to ringing and multiples from the reflection records. When the true reflection sequence is periodic, deconvolution will remove reflectors.

Apart from these points, the processing involved the standard steps. Figures 2 and 3 show results in 2D form of lines parallel (Figure 2) and perpendicular (Figure 3) to the geophone lines. Parallel to the geophone lines, the coal reflectors are smoothly varying. Several faults are apparent on the perpendicular lines.

1989 APPIN 2D/3D SURVEY

In October 1989, a second 3D survey was conducted near Appin at the invitation of BHP. This survey involved a novel combination of two-dimensional and three-dimensional techniques. BHP were already planning to shoot a survey along a square grid of lines at intervals of 250 m. Three-dimensional recording was achieved by laying out geophones along the survey lines perpendicular to the line undergoing shooting.

Two seismic systems were used for the work. The 96 channel system operated by Velseis Pty Ltd recorded the 2D data and the 48 channel system operated by the NSW Department of Mineral Resources and Energy recorded the 3D data. The systems were 'hard-wired' together to ensure simultaneous recording. In some instances shot holes were used for more than one shot.

Results of the survey have been processed and interpreted at Curtin University. No faulting is evident and the interpreted structure is consistent with the known geology. Tower Colliery will be mining in this area in the next few years.

P. HATHERLY, (ACIRL Ltd) and G. POOLE (BHP Steel Division)

1989 VIBRATOR TRIALS

Trials with the high frequency vibrator continued throughout 1989. In May, a 200 m 2D section was recorded near Cooranbong Colliery. This was followed by a period of further modification to the vibrator and then a further set of field trials near Appin in December 1989. Tests were conducted down a borehole and along a 600 m section of the second Appin 3D survey.

The vibrator is becoming increasingly more robust and reliable but there are still some important questions to be answered concerning the effective frequency range of the seismic signals and the depth of investigation.

1990 PROGRAM

During 1990, it is intended to conduct a further two 3D surveys. One of these is likely to be a mini-SOSIE survey in the Bowen Basin. It is hoped that the other will be in the Hunter Valley and involve the vibrator. Before this is undertaken, a further set of down-hole and 2D trials are planned. The project finishes in December 1990 and consideration will be made of the means of best providing an on-going capability in this technology.

CONCLUSIONS

The NERDDC funded 3D seismic reflection project is one of the most exciting developments in coal exploration in recent years. All aspects of the work have enormous potential:

- 3D surveying offers far improved subsurface coverage at an acceptable cost,
- the computer workstation offers significant time and cost savings as well as an improved result for the interpretation of 3D seismic data. These benefits also apply to 2D seismic interpretation, and
- the vibrator will be a viable surface source for seismic surveying.

ACKNOWLEDGEMENTS

This project has benefited significantly through the enthusiastic support and financial assistance of the collieries and geological staff at the various survey sites. Their assistance in the 1989 survey program is gratefully acknowledged.

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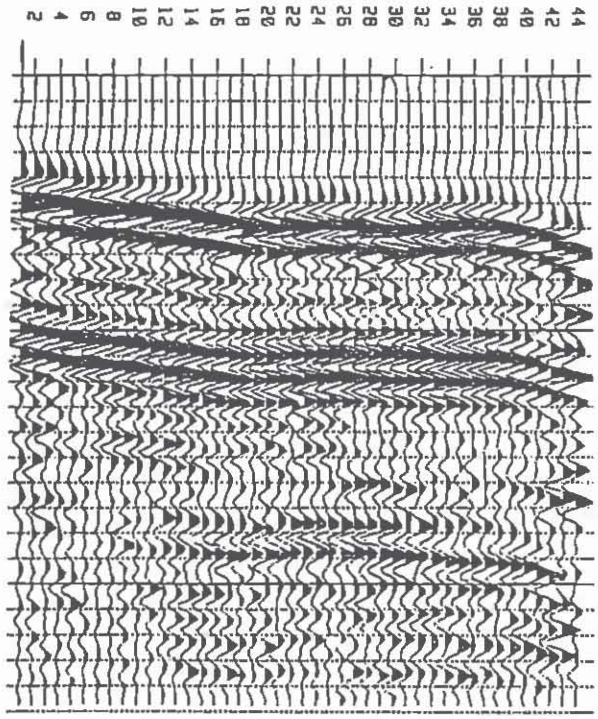

Figure 2. NS seismic section - German Creek 3D survey - trace interval 20 m

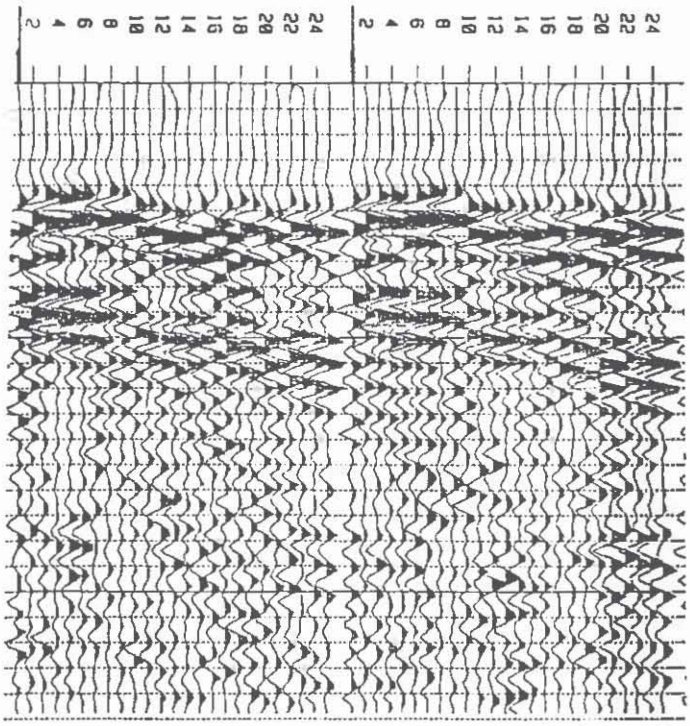

Figure 3. EW seismic sections - German Creek 3D seismic survey lines 20 m apart, trace interval 20 m.

THE APPLICATION OF BORE CORE SEAM DESORPTION DATA TO MINE PLANNING IN MULTI-SEAM ENVIRONMENTS

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ABSTRACT

The collection of reliable seam gas desorption data throughout the exploration programme for an underground coal deposit will enable the accurate prediction of seam gas emission levels and ventilation design. Well documented data currently exist on the relationship between mine production rates and gas emission levels for the Illawarra and Newcastle Coal Measures. However the multi seam environment, (e.g. Hunter Valley) generally has a greater hazard potential for gassy mine operations because of the number of seams in close proximity to the target seam. The following approach has been designed to quantify the seam gas hazard potential at an early stage and provide reliable mine design criteria in advance of mining.

1. Introduction

Coal production in some longwall operations is in excess of 10,000 tonnes per day, and it is crucial that exploration techniques target geotechnical hazards such as seam gas emissions, which may adversely affect that production. To optimise exploration expenditure, seam gas desorption data collection should commence during initial exploration drilling and identify the hazard potential as early as possible. The cost of a comprehensive first pass gas testing programme is approximately $15,000, which would represent a very small proportion of the total exploration budget for a proposed underground coal mine. Yet, the relative contribution to mine planning of such a programme may be very substantial.

The trends and inferences developed in this paper with respect to seam gas were derived from the MBGS data base which draws on data from the Wittingham Coal Measures (Sydney Basin), the German Creek Formation (Bowen Basin) and Moranbah Coal Measures (Bowen Basin).

A draft Australian Standard for the determination of desorbable gas content outlines two methods for the measurement and monitoring of the desorbable seam gas content. Although both methods ultimately provide the same result, MBGS has adopted the method recommended in the draft Standard.

2. Suggested Field/Laboratory Procedures

2.1 Desorption Equipment

The apparatus recommended for measuring and monitoring seam gas desorption is based on the natural desorption of gas from the bore core. The alternative technique relies on evolved gas displacing a "head" of solution, however this tends to induce a back pressure, which inhibits the natural desorption of seam gas. Many Australian coals are liable to differential desorption with back pressures as low as 40 kpa; a feature which does not appear to be as influential with many overseas coals. An important feature of a seam gas testing programme is the capability to compare natural desorption data from nearby exploration leases or mine sites with geology similar to that under study. Comparison tests using the two types of desorption apparatus conducted in the Moranbah Coal Measures show a difference in desorption rates. The shape of the desorption curve depends largely on the frequency of monitoring and in the case of the alternate technique the amount of "head" that the desorbing gas has to displace. Ideally, a desorbing coal sample has its own apparatus and is rarely closed except when transporting or refilling a measuring cylinder.

2.2 Potential Sources of Error

Provided that the apparatus is not faulty (leaks, etc.) the principal sources of error in recording and interpreting the total gas content of a core sample are:

* excessive time between core recovery and commencement of gas testing,
* temperature variations during test,
* air pressure variations during test.

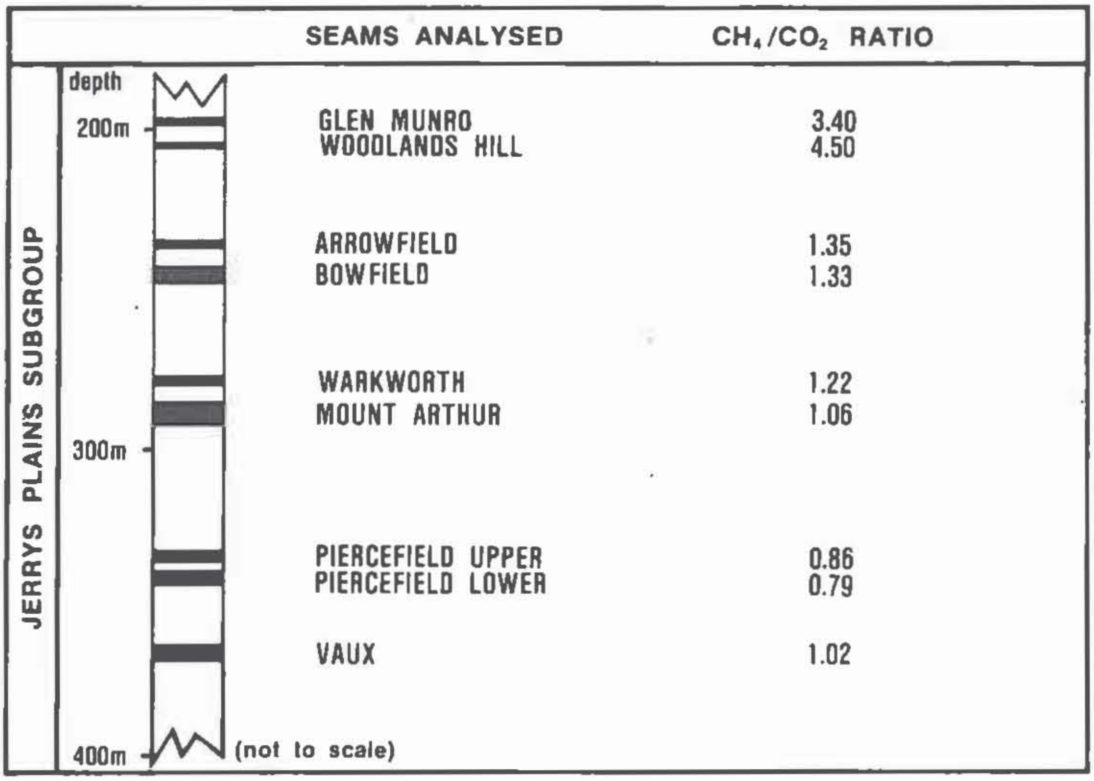
2.3 Seam Gas Analysis

Samples of desorbed seam gas should be collected at regular intervals during each test to determine the proportions of the component gases (generally methane and carbon dioxide). Marked changes in the gas components with time are not common, but the gas composition in one seam can vary substantially within the area of a mining lease. The variation in gas composition in seams at different stratigraphic levels can also be substantial (see Figure 1).

Figure 1

STRATIGRAPHIC VARIATION OF SEAM GAS COMPOSITION

LOWER HUNTER VALLEY



3. Reporting and Interpretation of Data

The parameters required for effective planning to control underground seam gas emissions are:

* the relationship between desorbable gas content (m^3/t) and depth
* seam gas composition
* gas desorption rate

In a multi-seam environment, these factors should be determined for **each seam**, not for the mining target seam only. The desorbable gas content/depth relationship and the seam gas composition are quantitative but the gas desorption rate is qualitative since it is largely controlled by the permeability of the coal sample. The desorption rate curve provides an indication as to whether the permeability rate is likely to be high or low, however a quantitative determination is difficult to obtain, (especially in the field) as permeability varies with gas composition, confining pressure and the presence of water. (Figure 2).

Detailed monitoring of desorption rates and seam gas emission modelling will assist the ventilation engineer in determining the relative proportions of seam gas emission from the face and underlying and overlying seams. Coal mined at the face is generally out of the mine within 2 hours of mining. Detailed comparisons between initial desorption rates indicates some coals are "fast" desorbers; for example the Goonyella Middle seam ($6.1m^3/t$) desorbs 30% of its total desorbable gas within the first 2 hours, (Figure 3). The Vaux seam ($6.3m^3/t$) in the Hunter Valley, on the other hand loses only 17% in the first 2 hours.

The contribution to the total mine gas from the longwall block during mining may often be substantially less than the contribution from overlying and underlying seams. Data from Central Colliery at German Creek indicates that at the time of mining, the face contributes less than 50% of the total gas make from the longwall operation (Figure 4). Studies of seam gas contributions in the multi-seam environment of the Hunter Valley provide evidence that face gas may contribute only 5%-15% of the total mine gas, while overlying and underlying seams contribute the remainder. The impact of surrounding seams on total gas make is illustrated in Figure 5.

A gassy coal mine really becomes a problem if the potential gas hazard is not identified and quantified before mining commences so that due allowance for the gas can be addressed during planning and development. Once seam gas has been identified as a positive hazard, other related investigations are necessary including:

* spontaneous combustion potential of all seams within proximity to the seam to be mined,

* incendive sparking potential of in-seam partings and immediate roof and floor strata.

A potential gas hazard, once recognized, will generally require that the strata be degassed in advance of mining, however some degassing options (Table 1) are expensive and may add considerably to production costs. Identification of the likely sources and quantity of gas is necessary in order to design practical solutions for degassing the mine strata.

Figure 2

COMPARISONS OF NATURAL DESORPTION RATES

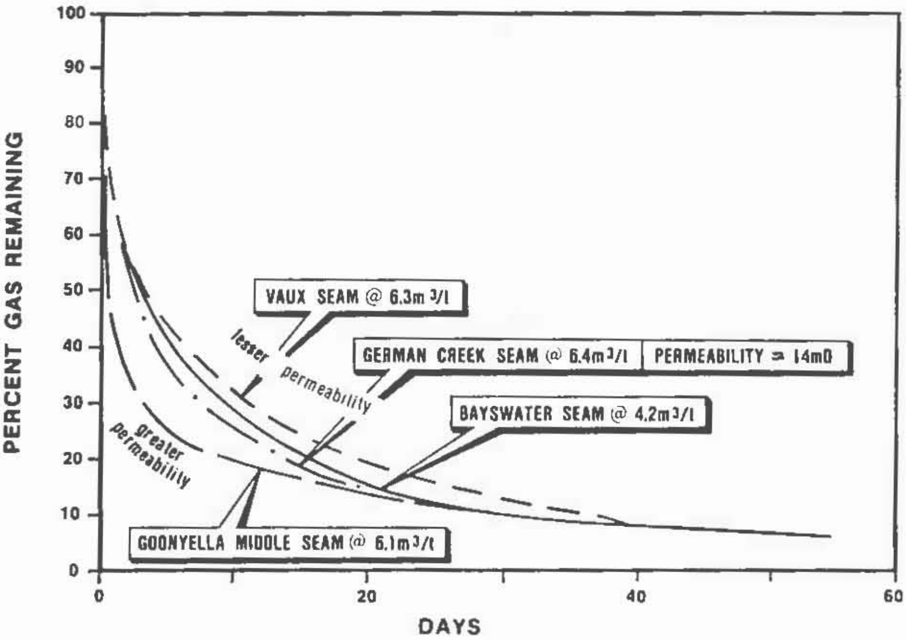


Figure 3

POTENTIAL WORKING FACE DESORPTION RATE

BASED ON INITIAL NATURAL DESORPTION

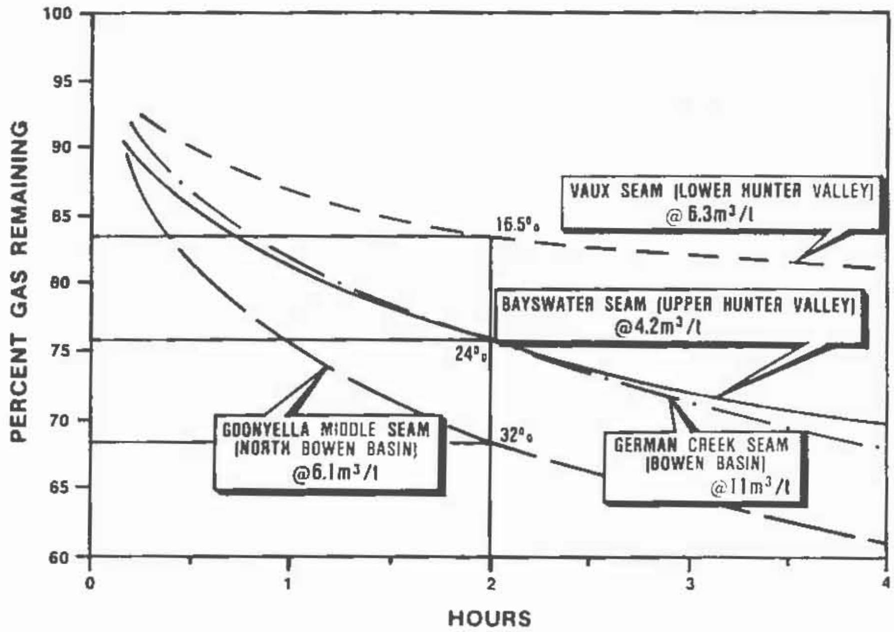
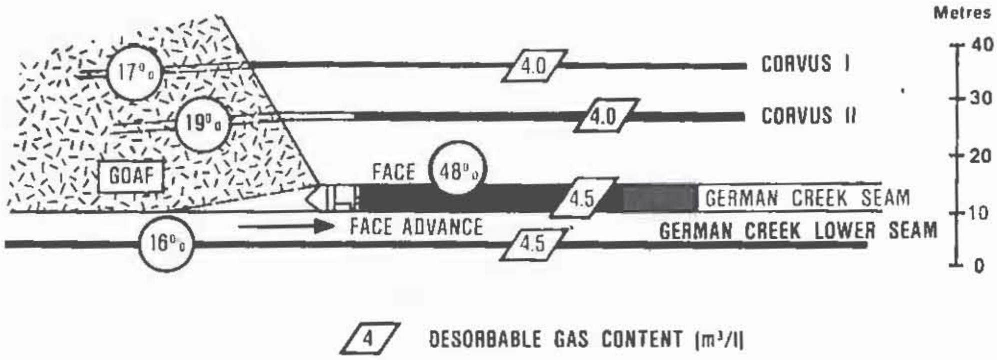


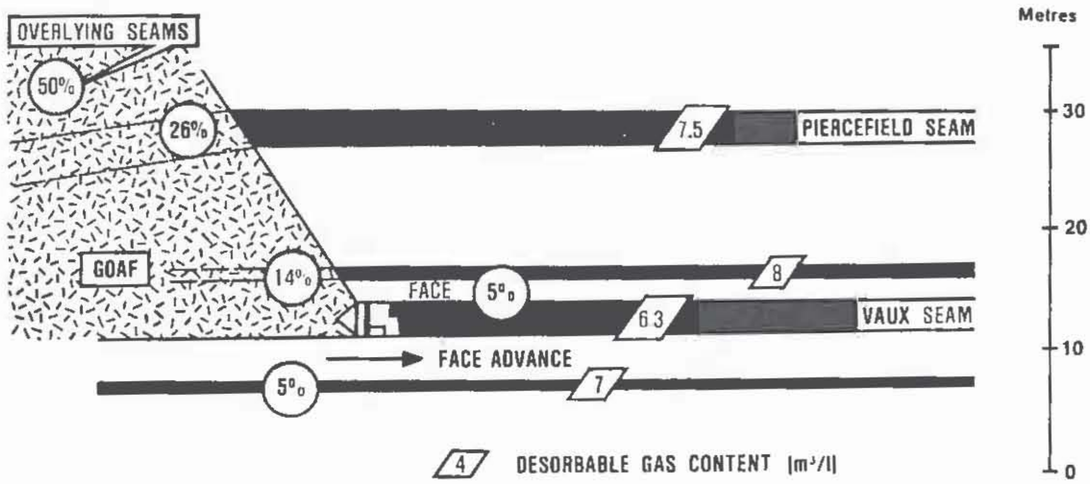
Figure 4

RELATIVE CONTRIBUTIONS TO MINE GAS PRODUCTION DURING LONGWALL MINING



GERMAN CREEK COAL MEASURES CENTRAL COLLIERY

(Seams not to scale)



JERRYS PLAINS SUBGROUP LOWER HUNTER VALLEY

(Seams not to scale)

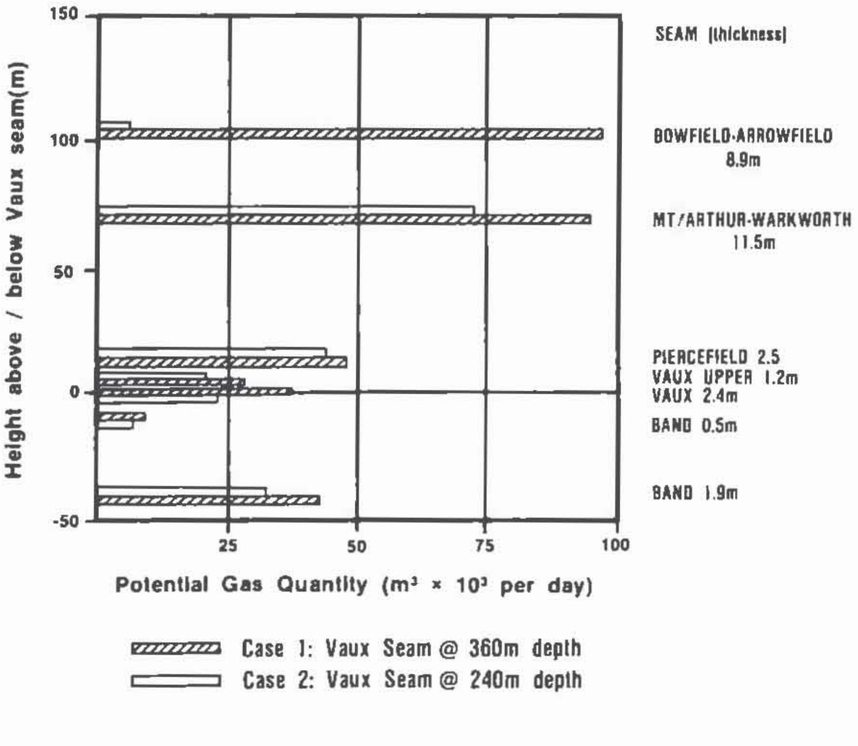
TABLE 1

PLANNING OPTIONS FOR GASSY MINES

Potential Degassing Option	Relative Cost	Limitations
Bleeder roadways	Low	Spontaneous combustion potential in goaf
Inseam longhole drilling	Mod	Not effective in multi seam environment,
Cross measure longhole drilling	Mod	Congestion in maingate
Goaf drainage from vertical drill holes	Low	Spontaneous combustion potential depends on CH_4 CO_2 ratio
High volume air flow	Low	Dust suppression
Three roadway longwall development	Mod	Slow longwall development
Additional ventilation shafts	High	Maximum amount of air through roadways
Booster fans in tailgates	Low	Statutory requirements

Figure 5

POTENTIAL INSEAM GAS STORED PROXIMAL TO A 6000 tonnes / day LONGWALL OPERATION



5. Future Seam Gas Emission Modelling Options

Presently the estimate of total gasmake from underground longwall mine operations is based on a series of graphs derived from European experience. The variations between the graphs are considerable and according to Battino (1988) have yielded unacceptably high discrepancies. Gas content is a site specific phenomenon and methane emission prediction may ultimately prove to be site specific as well. The modelling and prediction of seam gas emission should involve accurate geomechanical modelling of the strata, to determine the likely extent of disturbance above the worked seam. Finite element modelling of the limits and magnitudes of tensile stress zones of surrounding strata is necessary to establish the limit of increased strata permeability with goafing. In the near future three-dimensional multi seam analysis integrated with desorption data will increase the reliability of mine gas desorption predictions.

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COAL SEAM METHANE. PROBLEMS OF DETERMINATION, ADMINISTRATION AND UTILISATION

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Geological Survey of NSW

(This paper is submitted with the approval of the Director-General of the Department of Minerals & Energy)

INTRODUCTION

The coal seams of the New South Wales coal basins contain a vast resource of methane. The gas has been of interest principally because the inflow of significant quantities into coal mine workings is a danger to mine safety and reduces productivity.

The increasing depth of mining and the introduction of longwalls have increased the inflow into some mines so that it is now necessary to drain the gas from within the workings. In-seam drainage operations however only partially solve the gas problem.

Surface predrainage operations using hydraulic fracturing to stimulate gas production have been successful in the United States, Canada and Queensland. The technique has yet to be fully tested in this State but if successful will allow future mining areas to be partially drained well before mining commences. The technique could also allow the production of commercial quantities of gas from areas which will not be mined in the foreseeable future.

A number of organisations have commenced or will soon commence investigations into the use of surface predrainage techniques in the Sydney Basin. These investigations raise a number of issues. They include the utilisation of the gas, the legislative and administrative framework supporting the exploration for and the production of the gas, and the exploration for and the assessment of the gas resource.

COAL SEAM METHANE

The statement is often made that there is no production of petroleum in New South Wales. This is, of course, incorrect. The State's coal basins contain vast quantities of methane, and large volumes of the gas are released by underground coal mining. With several exceptions, the gas is vented directly into the atmosphere.

The methane, with smaller quantities of carbon dioxide, nitrogen, ethane and inert gases, is generated as a by product of the coalification process. Most of the methane is adsorbed on the coal surface within the matrix pore structure (Rightmire, 1984) but some is trapped as free gas in the fracture systems of the coal seams and the roof and floor rocks, is dissolved in the ground water within the seams, or is trapped within the pore spaces of overlying or underlying sandstones. The volume of methane within a seam increases with both the rank of the coal and with the depth of burial.

Coal seam methane has long been the province of ventilation and gas drainage engineers. Underground mining reduces the confining pressure on the coal enabling methane to desorb into the mine. Of greater significance is the effect of abutment pressure arches created in the floor and roof rocks of the workings. The pressure arches cause fractures to form to an extent roughly proportional to half the width of the extraction. Gas contained within coal seams or sandstones effected by the fracturing migrates along the fractures and into the mine. The conventional means of diluting and removing the gas is the ventilation system. The collected air and methane is subsequently vented.

Collieries operating at depths greater than 400 metres in the Southern Coalfield have always experienced high rates of gas make. This necessitated the careful design of ventilation systems and the installation of high capacity extractor fan systems. Even so, some of the collieries have had difficulty controlling gas emissions into the workings. As early as 1925, attempts were made at Metropolitan Colliery to pre-drain gas by drilling ahead of the workings (Hargreaves, 1982).

The introduction of longwall mining has greatly increased the volumes of gas flowing into mines. This increase is due, to the high rate of production, the greatly increased surface area of the seam exposed during mining, and the increased depth of effect of the abutment pressure arches. Fracturing can occur up to 80 metres below the seam and can in some instances cause the degassing of the entire coal measure sequence. Mining company representatives estimate that between 60% and 80% of gas entering the deeper South Coast collieries emanates from the underlying seams. Methane enters goaf areas for several years after a panel is mined and all seams down to and including the Tongarra are drained. The intake of gas is so large that conventional mine ventilation systems cannot control or remove it.

To prevent dangerous accumulations of gas occurring three methods of drainage are utilised. They are:-

- Horizontal holes drilled from the gate roads into the longwall block to drain the gas prior to mining.

- Inclined holes drilled from the gate roads into the underlying seams to drain gas during and after mining, and,

- Vertical wells drilled from the surface into sandstone reservoirs above the seam. Mining induced fractures allow the gas to seep into the wells.

The horizontal and inclined holes are cased and grouted for the first 3 to 5 metres, and gas is drained under negative pressure. Contamination with air occurs, and the gas collected consists of approximately 65% methane and 35% air.

In-seam drainage techniques are not, however, a total effective solution to the problem. Several collieries have been forced to shut down their longwalls because of high gas levels, despite extensive drainage facilities. The loss of production so caused is worth approximately $300,000 per day. Development headings for new longwall blocks are often not completed until 1 month before the mining of the block commences. Only a small proportion of the contained gas can be removed in time.

The difficulty of removing large quantities of methane is one of the key factors which will determine the viability of underground coal mining in NSW. Future operations will be conducted at greater depths and will require greatly increased levels of capital investment due to more difficult mining conditions. This will necessitate more effective gas drainage operations to ensure the high productivity levels required for the mines to remain competitive with overseas producers. Replacement areas for the South Coast collieries which will be needed within 10 years, are being delineated north of the Razorback Range, around Camden, Campbelltown and Narellan. In this region, the Bulli seam lies at depths of between 625 and 750 metres, and is between 3.5 and 5 metres thick. Underlying seams which will be degassed lie at depths up to 850 metres. In the Newcastle and Hunter Coalfields, some future mining will be conducted in gassy seams lying at depths greater than 300 metres.

PRODUCTION AND UTILIZATION OF COAL SEAM METHANE

Methane was produced from Balmain Colliery between 1942 and 1950, and was compressed for use in motor vehicles. The Australian Gas Light Company was granted Exploration Licence (PEL) 255 covering the Southern Coalfields in 1981. Later, the company acquired PEL 260 covering the central and eastern portion of the Sydney Basin. Investigations were undertaken towards the production of methane by the sinking of shafts and the drilling of a radial pattern of holes from the shafts into the coal seams. The shafts were to be sunk away from the mining operations, and the gas utilised by its addition into the reticulation system. The supply thus produced was to be an emergency reserve in case of damage to the Cooper Basin-Sydney pipeline. This plan proved to be uneconomic due to the high cost of sinking the shafts and the impermeable nature of the coal seams. The company also investigated the production of methane by in seam drainage from collieries. However, the gas produced is currently of insufficient purity to be added to the pipeline.

In the early 1980s, gas turbines were installed at BHP's Appin Colliery and at Kembla Coal and Coke's Westcliff Colliery to generate electricity by burning gas drained from the mines. At Appin, the power is fed directly into the grid but at Westcliff the power is used directly by the mine with any excess fed into the grid.

THE PRODUCTION OF METHANE BY SURFACE DRAINAGE TECHNIQUES

Hydraulic fracturing is the principal production enhancement technique used by the Petroleum Industry. It was first introduced in 1949 and has been extensively used since then to repair formation damage created by drilling, or to increase production from sandstones with low permeabilities. During the mid 1970s, the technique was first used by the US Bureau of Mines, to drain gas from coal seams. The first large scale pattern of wells was commenced in 1976. This was a joint project by the Bureau of Mines and US Steel Corporation (now USX Corporation) in the Warrior Basin of Alabama. This and other early experiments succeeded in demonstrating the possibility of production of significant quantities of methane at competitive prices. This success lead to the rapid acceptance of the technique and the rapid growth of the number of drainage projects in operation in a number of coal basins in Canada and the USA. The size of this section of the industry can be gauged by the fact that there were over 500 producing wells in the Warrior Basin by the end of 1988. In addition, 76 wells were drilled in the San Juan basin of Colorado and New Mexico during the second half of 1988. A number of the producing fields are located in areas where there is no coal mining.

Hydraulic fracturing is accomplished by the drilling of a well from the surface to intersect the target seam or seams. Water containing sand and a frothing agent is pumped under pressure down the hole and into the seam. The seam normally fractures vertically from the floor to the roof in one major direction. The fracture is called a "wing" and can extend more than 250 metres from the hole. The direction of the fracture is controlled by the residual stress fields in the seam. The sand fills the fracture and prevents it from closing when the pressure is released. When the hydrofracturing operation is completed, a pump is attached to the top of the hole and formation water is removed. Experience with United States operations shows that dewatering can take 3 to 4 months before the hydrostatic pressure in the hole is low enough to allow methane to desorb from the seam along the fractures and up the hole. The gas production starts slowly but increases for 6 to 9 months to its maximum and then falls slowly for 3 to 4 years. The content of the gas collected at the surface varies from hole to hole but usually consists of approximately 90-95% methane and the remainder carbon dioxide. The maximum rate of production and the number of holes needed to drain a hectare of coal vary depending on factors such as the gas content and permeability of the coal, the depth of the seam, and the length of the fractures. It should be noted that multiple seams can be hydrofractured in any well and that there is evidence to indicate that the technique does not cause any significant damage to the roof or floor rocks of the seams.

AUSTRALIAN DEVELOPMENTS

Early attempts at the production of methane by the hydraulic fracturing of coal seams were made in Queensland and in New South Wales in the late 1970's and early 1980's. In all cases, the attempts were considered unsuccessful because of poor gas production. At Appin Colliery, four holes were drilled in 1982 and multiple seams were treated in each hole. One hole, Appin 1, was drilled close to the mine workings. The Bulli seam was fractured and a fluorescent dye was added to the fluid. When the development heading reached the hole no trace of the fracture could be found. A full discussion of these early attempts can be found in Stewart and Barro, 1982. In 1987, Median Oil (now North Queensland Energy) commenced drilling and hydraulic fracturing operations in the Bowen Basin to the west of MacKay. 18 holes have been drilled to date, to intersect coal seams at an average depth of 500 metres. In 1988 Elders Resources Ltd acquired a share holding in the company.

The recent success of the operations in the United States, Canada, and the Bowen Basin has created enormous interest in the production of methane by surface drainage techniques in New South Wales.

The Coal Mining Industry

The surface drilling and hydrofracturing method has the potential to solve the gas problems experienced by collieries mining at depth. Holes would be drilled and treated up to 10 years prior to an area being mined, and the overseas experience suggests that between 50 and 55% of the seam gas would be removed. Kembla Coal and Coke Pty Ltd is planning to drill and fracture three test wells in the West Cliff Colliery Holding. BHP Engineering and USX Engineers and Consultants have set up Seam Gas Enterprises Pty Ltd to provide access to US technology and experience to Australian companies.

The Petroleum Industry

The hydraulic fracturing method has the potential to provide large volumes of pipeline quality gas for commercial uses. Command Petroleum N.L. purchased Sydney Oil Company in 1987 and took over the operation of PEL 267, covering Newcastle and the eastern Hunter. The company commenced the investigation of the methane resources of the Tomago Coal Measures in 1989. A well, Shearman 1, was drilled in October 1989 to provide coal samples for desorbtion testing.

Gold Charge Mining N.L. (formerly Tasman Gas Limited) has applied for a licence over the Southeastern Gunnedah Basin. The company proposes to drill and hydrofracture several wells to test the gas potential of the Black Jack Coal Measures.

The Electricity Commission

The Electricity Commission of NSW is examining the possibility of using gas turbines to generate intermediate and peak load power. To this end, it is also investigating potential sources of gas from within the State including the extraction of methane from coal seams independent of any mining operations. The Commission has applied for two petroleum exploration licences, one covering the western Hunter and one covering the coastal strip from Lake Macquarie south to Port Hacking.

UTILISATION

Surface predrainage techniques have yet to be proven viable in NSW. If however the test wells planned to be drilled over the next two years are successful and the gas can be produced at a reasonable cost, then the State may have a significant domestic production within 10 years. There are a number of options for the utilisation of the gas. They include:-

- methane could be used by the Electricity Commission as fuel for gas turbines.

- methane could be sold by the producer directly to a consumer. The Gas Act, 1986 permits the sale of gas to up to 5 consumers before the supplier is considered a gas company and is effected by the major provisions of the Act.

- methane could be burned as fuel in gas turbines at collieries to supply the mines with electricity.

- the gas could be sold to AGL and added directly to the reticulation system. However, AGL is contracted to its Cooper Basin suppliers until the year 2006.

Research into other possible options has been commenced. The utilisation of the gas will benefit the State because the methane resource will not be wasted. It will also benefit the environment because methane is recognised as contributing to the "greenhouse effect".

LEGISLATION AND ADMINISTRATION

Coal seam methane is petroleum and the administration of its exploration and production is normally covered by the Petroleum Act, 1955. In 1988, the Minister for Minerals and Energy approved policy guidelines to prevent conflicts between the Petroleum Act and the Coal Mining Act, 1973, especially where methane drainage is an essential part of coal mining operations. In essence, the guidelines mean that colliery holdings will generally be excluded from petroleum exploration licences. Investigations and development of petroleum within colliery holdings will normally be covered by way of Section 72A of the Coal Mining Act.

If surface pre-drainage techniques can be made to work effectively in the Sydney Basin, then coal companies will want access to future coal reserves up to 10 years prior to mining. This long lead time will be necessary to allow as great a proportion of the stored gas to be drained as possible. Some mechanism may need to be developed to permit access to areas outside the current colliery holdings and which are covered by petroleum licences. Access to drill sites will also need to be ensured in any future surface development planned over replacement coal mine areas particularly in the Southern Coalfield.

EXPLORATION

There is little quantitive data available about the methane resources of the State's coal basins. In the Sydney Basin, the gas desorption testing of coal seams has been carried out by few organisations and in restricted parts of the basin. So little is known that only broad estimates of the size of the resource can be made. The exact relationship between, rank, depth and gas content has yet to be determined as has the reasons for large variations in gas content in individual seams and for lateral variations in CO_2 content. It is now vital that a data base on coal seam methane be built up and that desorption testing be carried out wherever possible on seams intersected at depths below 300 metres. This is necessary not only to ensure that the resource can be usefully utilised but also that data is available for future mine planning.

The Department of Minerals and Energy is now conducting desorption testing routinely in its coal drilling programmes. The experience to date has shown that there are some difficulties with field testing proceedures and with the testing apparatus. Great care must be taken to ensure that the desorption results do give (as far as is possible) an accurate measure of seam gas content.

It may be useful for discussions to be held with the various interested organisations so that standard simple and accurate procedures can be introduced.

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'RAMBOE' – A THERMAL MATURITY TECHNIQUE FOR OIL EXPLORATION BASED ON THE RAMAN AND FLUORESCENCE PROPERTIES OF COAL MACERALS

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A new thermal maturity technique has been developed for use in oil exploration based on the Raman and fluorescence properties of organic matter in sediments.

It was known that the Raman spectrum of vitrinite in coal changes subtly with rank and we therefore considered the possibility that this could form the basis of a thermal maturity technique using the laser Raman microprobe. This is a relatively new instrument and its use enables spectra to be obtained from particles of dispersed organic matter in sediments that are just a few micrometres in dimensions.

Development of a technique to a level required for routine examination of organic matter required firstly the solution of two problems - high maceral fluorescence that can mask the Raman spectrum, and the tendency of the sample to burn in the focused laser beam. In addition, in the region of the zone of oil generation, changes in the Raman spectra of macerals are quite subtle and it was apparent from the outset that efficient methods of mathematical and statistical evaluation of the data would be required.

A detailed study showed that with a careful choice of irradiation conditions, high maceral fluorescence and burning were not insuperable obstacles to the development of a thermal maturity technique with the laser Raman microprobe. Indeed it was shown that the fluorescence spectrum on which the Raman spectrum is superimposed provided a useful thermal maturity parameter in its own right.

Under the standard conditions we have established, Raman spectra in the range 1000-2000 cm-1 can be obtained from all macerals with the exception of some vitrinites and liptinites of low thermal maturity. Modification to the instrument control software has enabled fluorescence to be studied as a function of time. The fluorescence alteration curves have a characteristic form which is strongly dependent on thermal maturity, and to a lesser extent, on maceral composition in the vitrinite - inertinite series. The alteration behaviour of vitrinite and inertinite is different to that of sporinite and cutinite.

The basis of the calibration of the RAMBOE technique against vitrinite reflectance was the systematic study of the Raman and fluorescence properties of a range of liptinite, vitrinite and inertinite macerals in thirteen reference coals selected mainly from the Sydney and Bowen Basins together with some Australian lignites and sub-bituminous coals.

Two statistical analyses of this data were carried out in parallel. One based on principal component analysis was carried out in the CSIRO Division of Mathematics and Statistics. The other, based on multi-linear regression using parameters obtained from the fluorescence alteration curves and by decomposition of the Raman spectra, was pursued as part of the main program for technique development. Both approaches led to the important result that the mean equivalent vitrinite reflectance of a population of vitrinites or low reflectance inertinites can be determined with reasonable accuracy by statistical analysis of spectroscopic data on four or five grains.

Automation of procedures for acquisition of the spectral data has been enabled by the construction of a stepping stage which is programmed to sequentially acquire spectral data on a small number of pre-selected maceral grains for the subsequent calculation of the equivalent vitrinite reflectance of the sample.

An APIRA project has been completed in which the RAMBOE technique has been applied to the determination of thermal maturity of organic matter in material from a number of Australian sedimentary basins ranging in age from Tertiary-Cretaceous to Lower Palaeozoic.

ISOTOPIC AND FLUID INCLUSION STUDIES OF FLUID FLOW HISTORY IN THE NARRABEEN SANDSTONE

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INTRODUCTION

This study is an integrated approach to investigate pore water evolution during burial of Narrabeen Group sandstones by combining petrological examination together with stable isotope and fluid inclusion analyses.

The Narrabeen Group sandstones comprise potential reservoirs for hydrocarbons. However, the potential varies greatly from one sandstone body to another as a result of porosity and permeability modifications due to diagenesis. This study enhances the understanding of the diagenesis of the Narrabeen Group sandstones for better prediction of potential reservoirs.

The sandstone samples used in this study are from eight boreholes in the southern portion of the Sydney Basin (Figure 1) and were selected from the Scarborough to Upper Bulgo Operational Units (Figure 2).

PARAGENETIC SEQUENCE

From petrological examination and scanning electron microscope/energy dispersive X-ray analyses, a generalized paragenetic sequence is deduced (Figure 3). This sequence is modified from the one by Bai (1988) following petrological examination of more samples. Early grain-coating chlorite and late carbonates (Figure 4) are additionally recognized cement phases.

Diagenesis of the Narrabeen Group sandstones began with the formation of early clays and small authigenic quartz euhedra. Early kaolin crystallized in sands with oxygenated and mildly acidic pore water whereas early grain-coating chlorite crystallized in sands with anoxic and neutral to mildly alkaline pore water. Following the formation of these early clays, major carbonate cementation took place. Among the diagenetic carbonates, grain-coating calcite was the first to crystallize and was succeeded by grain-coating siderite, pore filling calcite, pore filling siderite, and pore filling ankerite. After the major carbonate cementation, stacks of kaolin booklets and quartz overgrowth crystallized. Illitization of mixed layer clays occurred throughout much of this carbonate and silicate diagenesis. The latest cements to form were calcite, ankerite and authigenic, filamentous pore-bridging illite.

FLUID INCLUSIONS

The sandstones used in this study contain abundant quartz overgrowths. Within quartz overgrowths and between the detrital quartz grains and overgrowths, liquid-gas inclusions are usually recognised. The homogenization temperature of these inclusions in four samples taken from drilling depths of ca 0.5 km range from 95 to 120°C, which is about 40 to 80°C higher than current formation temperatures.

The higher temperatures may have resulted from higher heat flow than the current value of 1.7 to 2.1 HFU or greater depth of burial due to an uncertain thickness of eroded section. If the eroded section is assumed to be 500 to 1000 m thick the formation temperatures of quartz overgrowths would be 102 to 130°C (Figure 5). Middleton and Schmidt (1982) also have suggested loss of ca./km sediment thickness by erosion following uplift. Vitrinite reflectance values and overprinted magnetizations were modelled in terms of thermal history and indicated rapid cooling at 100-70 Mabp.

STABLE ISOTOPES

When an O-bearing diagenetic mineral is precipitated from pore water, there is a temperature dependent fractionation of oxygen isotopes between the pore water and the mineral. The temperature dependence is of the form $10^3 \ln\alpha = AT^{-2} + B$ where A and B are constants, T is temperature in °K, and α is the fractionation factor equal to $(10^3+\delta^{18}O_{mineral})/(10^3+\delta^{18}O_{water})$. The specific equations for kaolin, illite, calcite, siderite, ankerite, and quartz are known.

The interdependency of temperature and $\delta^{18}O$ of pore water means that if one is known or can be assumed the other can be calculated from the measured $\delta^{18}O$ of the diagenetic mineral.

PORE WATER EVOLUTION

At the time of Triassic sedimentation the Sydney Basin was at high latitudes where depositional meteoric waters are ^{18}O-depleted and $\delta^{18}O$ is estimated to have been -20°/$_{oo}$ to -15°/$_{oo}$. Early diagenesis would have involved pore-waters of similar $\delta^{18}O$ of -18°/$_{oo}$ for precipitation at 20°C of the earliest siderite phase. Using fluid inclusion homogenisation temperatures and $\delta^{18}O$ of quartz overgrowths to calculate pore water $\delta^{18}O$ suggests ^{18}O-enrichment of 10°/$_{oo}$ by the time of late quartz diagenesis. Using this sort of approach and the relative timing of the other diagenetic cements enables a pore-water evolution path to be constructed (Figure 6). The ^{18}O-enrichment depicted between early siderite and quartz overgrowth is typical of burial diagenesis (e.g. Eadington et al

1989) and is a consequence of dissolution of ^{18}O-rich detrital minerals.

The last diagenetic phase - illite is of particular interest. As indicated in Figure 6, it could have formed under two different conditions. If precipitated at a higher temperature than quartz overgrowths, there would have been a significant jump in $\delta^{18}O$ of pore water. This implies that new, more ^{18}O-rich pore water from deeper underlying sediments should go through the Narrabeen Group sandstones prior to the formation of illite. If illite was formed at a lower temperature than quartz overgrowths the trend of increasing $\delta^{18}O$ of pore water ceased or reversed prior to illite formation. This implies flushing of meteoric water through the Narrabeen Group sandstones as a result of uplift of the Sydney Basin. Our intention to apply K-Ar dating techniques (see Hamilton et al., 1989) to these illites should result in well founded constraints on the age of Sydney Basin uplift.

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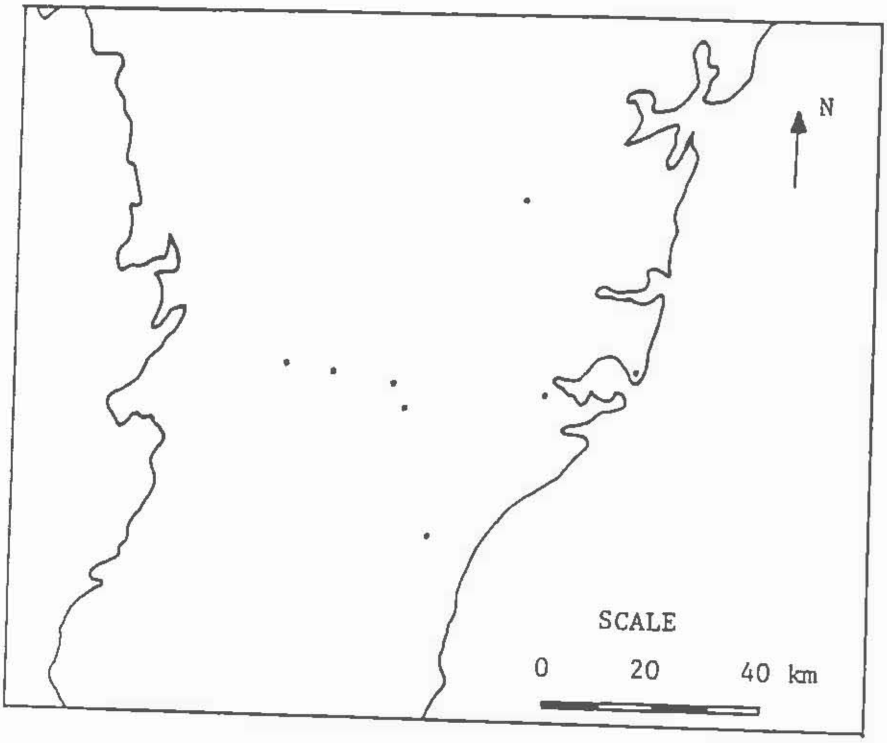

Figure 1. Locations of sampled boreholes in the Sydney Basin

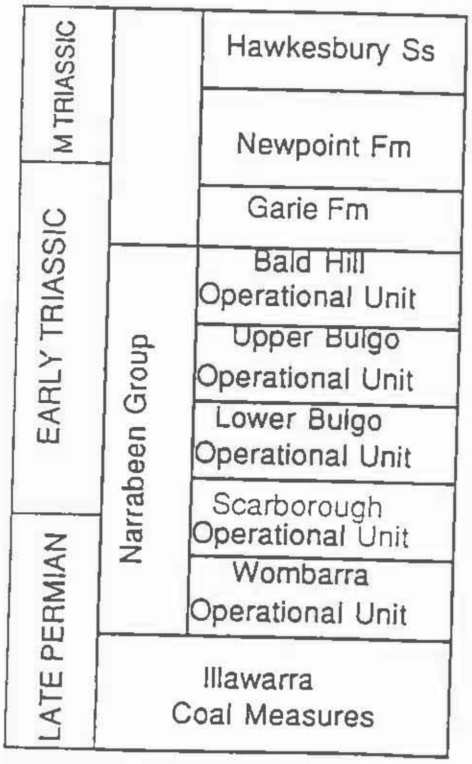

Figure 2. Generalized stratigraphic column

Time

	Early			Late
Chlorite	x			
Kaolin	x			-xx-
I/S to illite		--------------------------	--------------------------	--------------------------
Calcite	x	xx		x
Siderite	x	xx		
Ankerite			xx	x
Quartz	x			-xx-
Illite				-x x-

Figure 3. Generalised paragenetic sequence

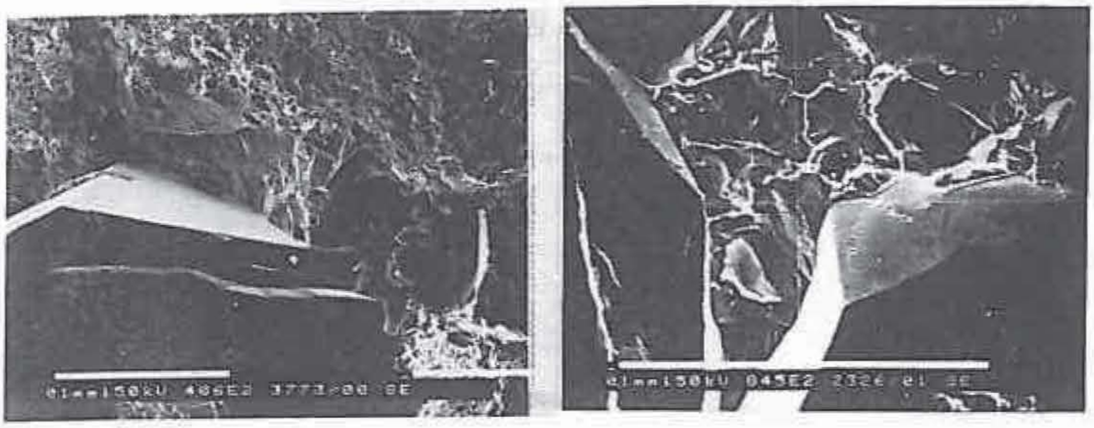

Figure 4. SEM photographs of late diagenetic carbonates showing calcite (left hand photo) and ankerite (right hand photo) overlying quartz overgrowths

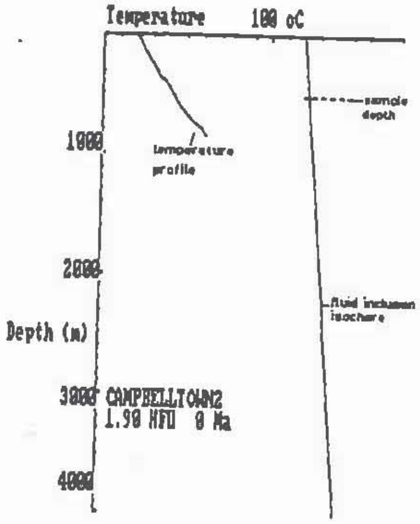

Figure 5. The fluid inclusion isochore and temperature profile for the Lower Bulgo operational unit, Campbelltown 2 borehole. The gap between the temperature profile and isochore indicates the temperature and depth during quartz cementation. At current heat flow a depth of about 2800 m is required to satisfy the fluid inclusion isochore. Alternatively, if heat flow were higher, say 3 HFU, then a depth of about 1400 m is required.

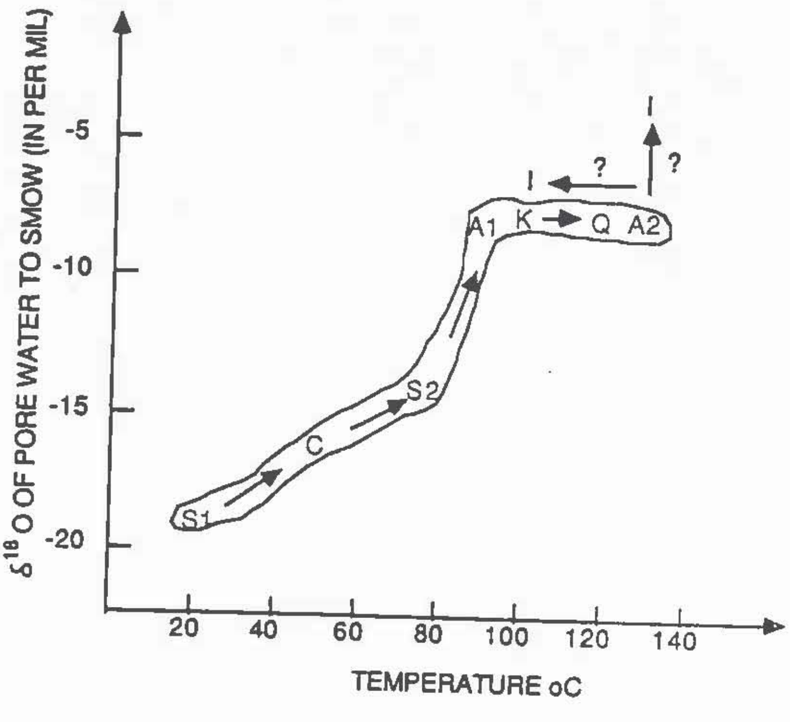

Figure 6. Evolution of pore water oxygen isotope composition with burial temperature, also showing formational conditions of the various diagenetic minerals - siderite (early S1, late S2), calcite (C), ankerite (early A1, late A2), kaolin (K), quartz overgrowths (Q), and illite (I)

THE APPLICATION OF CROSS-HOLE SEISMIC (CHS) AND IN-SEAM SEISMIC (ISS) IN THE DETECTION OF OLD MINE WORKINGS

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INTRODUCTION

In Seam Seismic (ISS) and Cross Hole Seismic (CHS) survey techniques have been successfully used to locate old underground workings in a coal mine.

The colliery is planning to drive main development headings into an area which had been previously mined 30 years ago. It was known from old mine plans that bord and pillar first workings existed to the north of the line of the proposed development, however the accuracy of the old mine plans was unknown. As no underground access was available to the abandoned mine it was decided to use CHS and ISS to attempt to delineate the southern boundary of the old mine workings. This paper describes the survey procedures and discusses the survey results with their respective interpretations. The results clearly show that ISS and CHS are valuable tools for use in operating coal mines.

SURVEY PROCEDURE

A series of five 15 cm diameter boreholes marked A to E on Figure 1 were drilled. The depth to the coal seam was approximately 200 to 220 metres while the seam thickness was approximately 2.5 metres. All boreholes were geophysically logged.

Four of the boreholes were positioned on the west side of the predicted position of the old workings (boreholes B to E), while the other borehole (A) was positioned to the east.

Three component geophones were grouted into boreholes C and E in a mid seam position. Borehole A was used as a shothole only, borehole B was used as both a shot and geophone hole, while borehole D was used as a geophone hole only.

Boreholes A and B were used as shotholes for the collection of ISS data. Four shots were fired in-seam in borehole A at depths of 219.8 metres, 219.2 metres, 218.5 metres and 217.9 metres with ISS data being collected in boreholes B, C, D and E. Three shots were then fired in borehole B at depths of 209.7 metres, 209.1 metres and 208.5 metres with ISS data collected in boreholes C, D and E as shown in Figure 1.

The four shots fired in the coal seam in borehole A were recorded into 24 channels as follows.

Channels 1 to 3-XYZ three component grouted geophone borehole E
Channels 4 to 12-nine geophones in the string in borehole D
Channels 13 to 15-XYZ three component grouted geophone borehole C
Channels 16 to 24-nine geophones in the string in borehole B

The three shots fired in the coal seam in borehole B were recorded into 15 channels as described above except that channels 16 to 24 were disconnected and the geophone string removed.

Borehole A was used as the source hole for the two CHS tomographic images. Shots were fired at intervals of 6.1 metres from 304.8 metres for the deepest shot to 36.6 metres for the shallowest shot. Two geophone strings containing 21 channels each were located in borehole B and D.The depths of the geophones ranged between 99 metres and 299 metres in borehole B and between 112 metres and 312 metres in borehole D. Geophone spacing in each string was 10 metres.

ISS TRANSMISSION RESULTS

The data from shots fired from borehole B into boreholes C, D and E was used as a reference as it was assumed that the coal was undisturbed between these boreholes.

The dispersion curve of one of these traces is shown in Figure 2. When compared with the mathematical curves calculated for this site the field results indicate a disturbance of the seam wave.

Analysis of the ISS transmission data between borehole A and boreholes B, C, D and E showed the following

Boreholes

A-BNo Channel Waves
A-CWeak Channel Waves
A-DWeak Channel Waves
A-EWeak Channel Waves

The data obtained was generally characterised by weak channel wave energy compared to a relatively strong compressional wave. Where channel wave energy could be detected, the majority was composed of Rayleigh waves.

The reason for the relatively poor development of channel waves in the data between boreholes A and C, D and E over a transmission distance of 250 metres has been interpreted as being due to a geological disturbance. As can be seen in Figure 1 the western side of the old mine workings stop on a straight line trending west of north. Roof support practice in the early 1950's when the mine closed was rudimentary. Even a relatively minor fracture zone may have caused roof failure stopping mine development. This fracture zone is also considered as the reason for the poor quality data in Figure 2, as the data was received from shotlines close and parallel to the zone. The seismic waves have travelled through broken coal adjacent to the fracture zone effecting the development of Love waves.

The exact location and nature of the disturbance cannot be determined from the data set alone, however it does appear that Rayleigh wave propagation is not influenced as much as Love wave propagation and that greater attenuation of shear wave components than compressional wave components has occurred. This leads to the conclusion, supported by theoretical modelling that the geological disturbance may be a fracture zone rather than a fault.

CHS TOMOGRAPHY RESULTS

An Algebraic Reconstruction Technique (ART) algorithm was used to process the conditioned arrival time data using the Back Projection Technique (BPT) to establish an initial velocity field. A processing pixel size of 5 metres was used.

Tomograms were calculated for two borehole pairs, A-B and A-D respectively.

A difference tomogram was then computed by first smoothing the tomograms of the two borehole pairs and then subtracting the velocities of one tomogram from the other. The resulting tomogram showed that there are regions of significant velocity differences between the two original tomograms. It is known that there are no major stratigraphic changes between the boreholes, therefore the differences found are considered to be due to the presence of the old mine workings. The position of the feature on the difference tomogram also corresponds to the position of the old mine workings on the mine plan (Figure 1).

CONCLUSIONS

The ISS transmission data from borehole A to borehole B and the CHS tomography survey successfully confirmed the occurrence and the location of the old mine workings in this area.

Furthermore the ISS transmission data gained from the shots from borehole A to boreholes B, C and D discovered a previously unknown geological disturbance.

ISS transmission and CHS tomography have been shown to be useful tools to assist geologists and mine planners in the delineation of old mine workings in a coal measure environment.

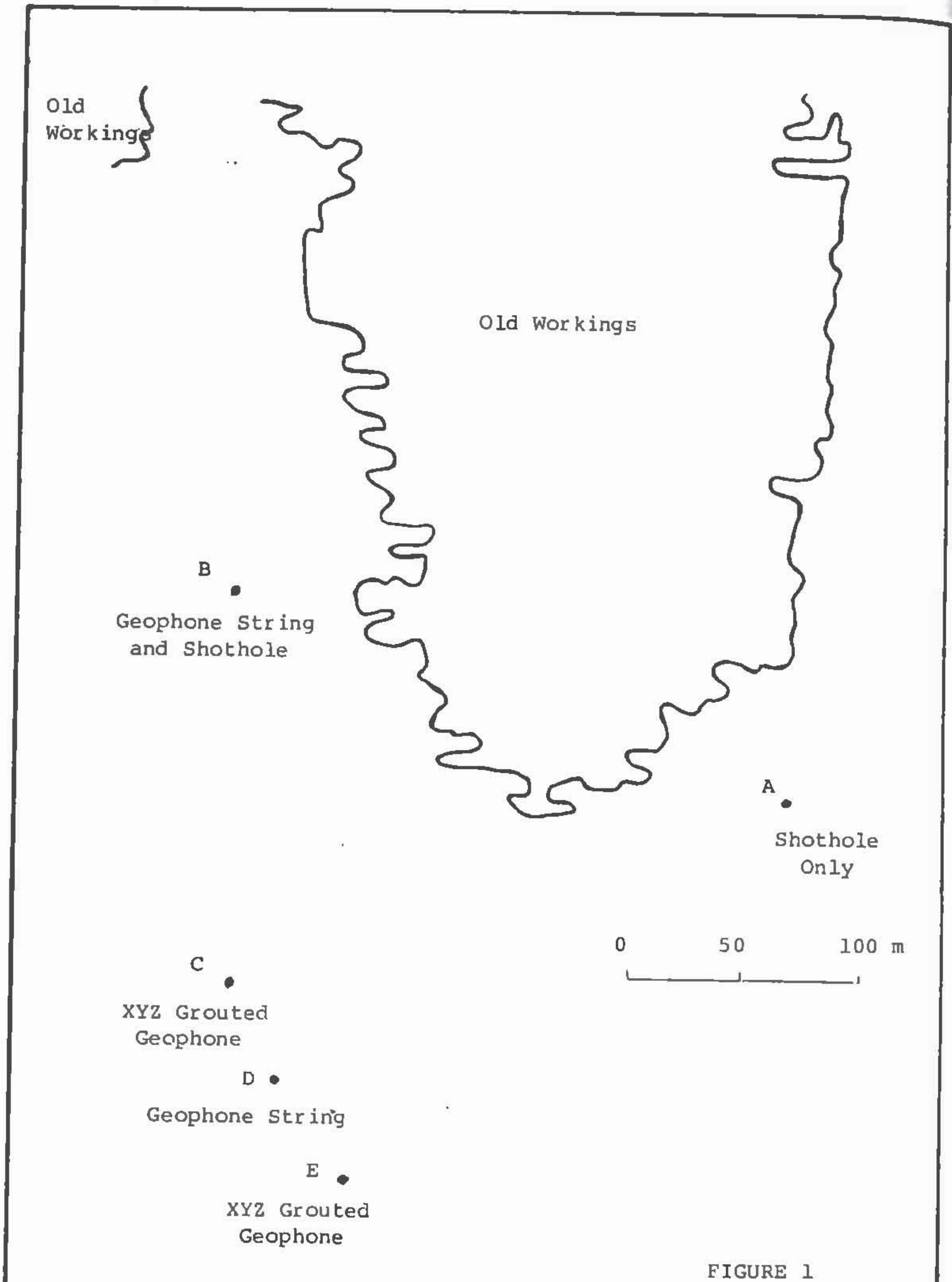

FIGURE 1

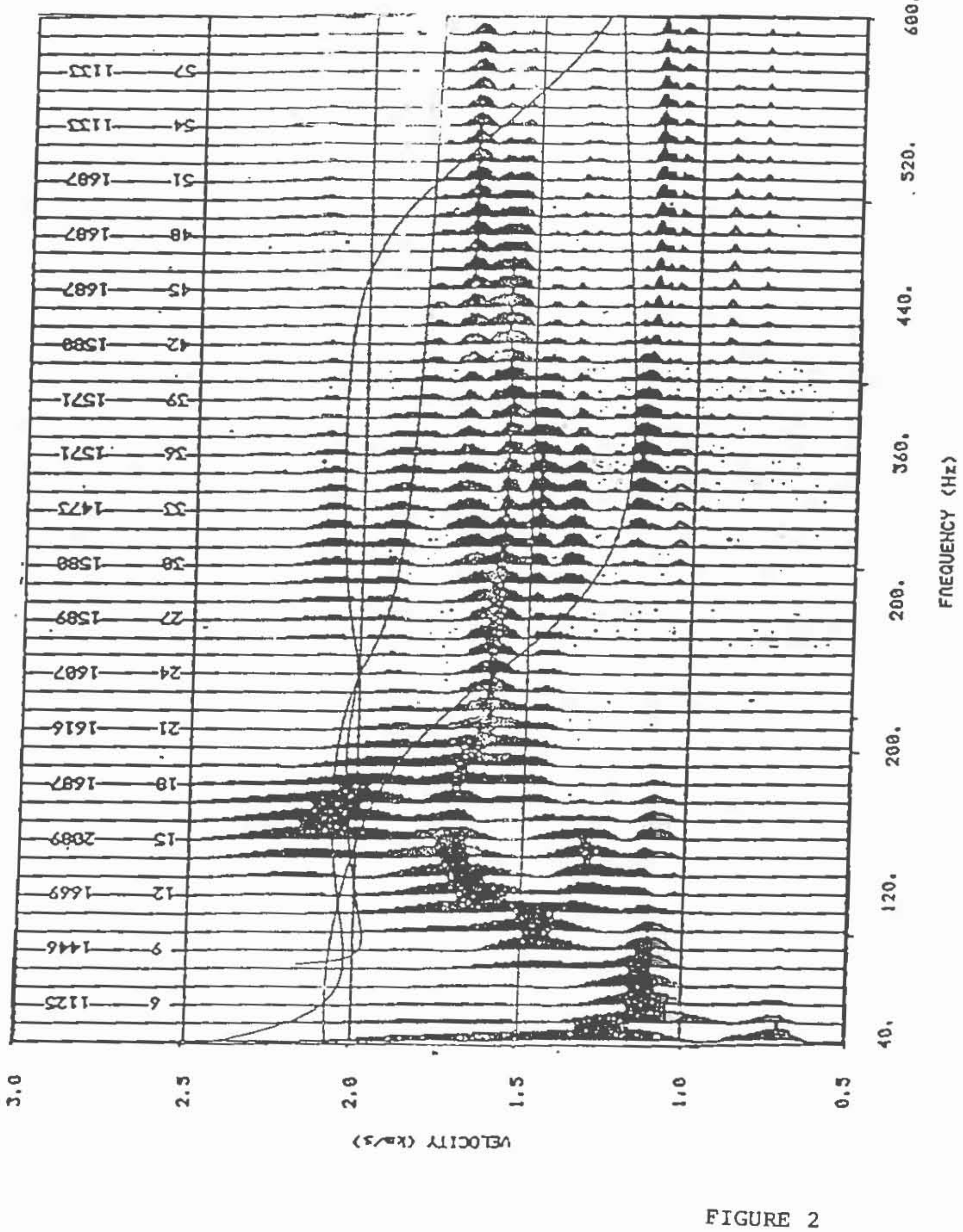

FIGURE 2

GEOPHYSICAL DETECTION OF OLD MINE WORKINGS

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INTRODUCTION

Means of detecting voids in the subsurface are required for military reasons, civil engineering and mining engineering. The voids may be natural as in the case of limestone caverns, or man made as in the case of tunnels and mine workings. Requirements exist for their detection almost regardless of their size or depth. They may be filled with water, air or other material.

Geophysical means of void detection have yet to be fully established. Ground probing radar is perhaps the most reliable technique but its application is usually restricted to relatively shallow voids (less than 10 m) in electrically resistive rocks. Other possible techniques include seismic reflection, gravity, and various resistivity and electromagnetic techniques.

In the Newcastle region, there are many areas containing old mine workings which impact on engineering design and construction. In 1989 ACIRL and the RTA conducted trials of some of the geophysical methods with the potential to map shallow mine workings. The trials were conducted in an area of bushland over part of the proposed route for State Highway 23 at Charlestown, less than 1 km from the University of Newcastle.

ACIRL trialled the Controlled Source Audio Frequency Magneto Telluric (CSAMT) method, the Very Low Frequency (VLF) Method and Ground Radar. The surveys were conducted by World Geoscience Corporation, Macquarie University and Georadar Research respectively. Separate to these, the RTA commissioned Dr R. Whiteley to conduct a SIROTEM survey and Mr L. Acimovic to conduct separate VLF and resistivity surveys.

ACIRLs work is described herein. This and the other results will be presented to the conference.

P. HATHERLY (ACIRL Ltd) and G. WON (RTA)

SURVEY SITE

At the survey site, the Borehole Seam has been mined in a tunnel and cut-through operation. The old mine plans on record indicate that the roadways are about 10 m wide and the pillars some 40 m long and 5 m in width. The plans indicate that there was total extraction but given that boreholes drilled in the area have intersected voids at seam level, it appears that at least some of the workings are still standing.

The locations of each survey are shown in Figure 1. The radar survey mainly concentrated in an area where the workings were thought to be at a depth of about 5 m or less. Uneven, 'hummocky' ground in these areas is suggestive of extensive collapse. The survey also extended to BH 14 where the depth to seam is about 14 m. The CSAMT survey was very detailed and conducted over BH 13 where the depth of the workings is 33 m. ACIRL's VLF survey was conducted over the site of the CSAMT test as well as at BH 14 and a shallower site to the north. The RTA's SIROTEM, resistivity and VLF surveys were located around BH 14.

VLF SURVEY

In VLF surveys, the source of electromagnetic waves is the world-wide VLF communications network. For Australia, the base at NW Cape (22kHz) is the strongest source of VLF transmissions. Surveys involve measuring the resultant electric and magnetic fields at the ground surface. This allows calculation of a resistivity and phase.

The Newcastle survey involved three EW lines each 108 m long. Measurements were made at 2 m intervals using a Geonics EM16R two channel receiver. The electric field was measured between two electrodes inserted in the ground at a nominal 9 m separation along the profile line. The magnetic field was measured perpendicular to the profile line by a magnetometer.

The results of the VLF survey show significant variability in apparent resistivity but the the peaks and troughs in the profiles are irregularly spaced and are not immediately suggestive of the presence of subsurface workings. However, assuming a 30 ohm-metre surface resisitivity, the depth of penetration is only about 15 m.

On line 1, the depth of workings is 33 m and it is unlikely that the VLF survey is responding directly to these. On lines 2 and 3, the depth to workings is 14 m or less. If the workings under these lines are collapsed, as suggested by the presence of the hummocky ground, regular patterns of resistivity anomalies need not be expected.

The VLF survey, therefore, appears to be responding to subsurface features indicative of collapse in the old workings at shallower depths. In the deeper areas, near surface features only are being detected. These may be associated with the underlying workings.

To further test these suggestions, VLF data from closely spaced parallel lines, similar to those employed in the CSAMT survey, are needed to map the lateral extent and trends in the VLF resistivity anomalies.

CSAMT SURVEY

In the case of a CSAMT survey, a current generator is used to produce an electric field which propagates through the air. As with the VLF signal, the field interacts with the earth. The resulting electric and magnetic fields within the earth are indicative of the subsurface geology.

CSAMT surveys permit measurements to be made at a range of frequencies from close to DC up to about 12 kHz. This leads to different depths of investigation with the lower frequencies having a proportionally greater depth of penetration. Signals are also much stronger than in VLF work. This allows the electric field electrodes to be more closely spaced (2 m in this case) with a corresponding improvement in detail.

This survey is believed to be the first use of CSAMT in void detection anywhere. It involved two parallel EW traverse lines, 30 m in length and 5 m apart. The trend of any anomalies (ie the workings) would be shown by comparison of the results from each line. Two separate transmitter stations were located to the west and south of the traverse lines to allow field measurements to be made in two directions. This was to ensure that any anomalies due to poor receiver coupling could be identified.

The CSAMT survey has produced very encouraging results. As shown by the pseudo section in Figures 2, there are vertical zones some 5 m in width with higher resistivity every 12 to 15 metres. These are on both survey lines and were independently observed for both transmitter locations. When the results for the two lines are correlated as in Figure 3, a north-easterly trend to the resistive zones is indicated.

Given the width and spacing of the anomalies and their trend, a relationship between the resistivity anomalies and the old workings is immediately suggested.

Such a relationship is supported by one dimensional inversions conducted on the observed data. For reasons of computational complexity, full three dimensional variations in subsurface geology were not considered but the inversions show discrete resistive anomalies at depths of 30 to 40 m - the deoth of the workings. Our

P. HATHERLY (ACIRL Ltd) and G. WON (RTA)

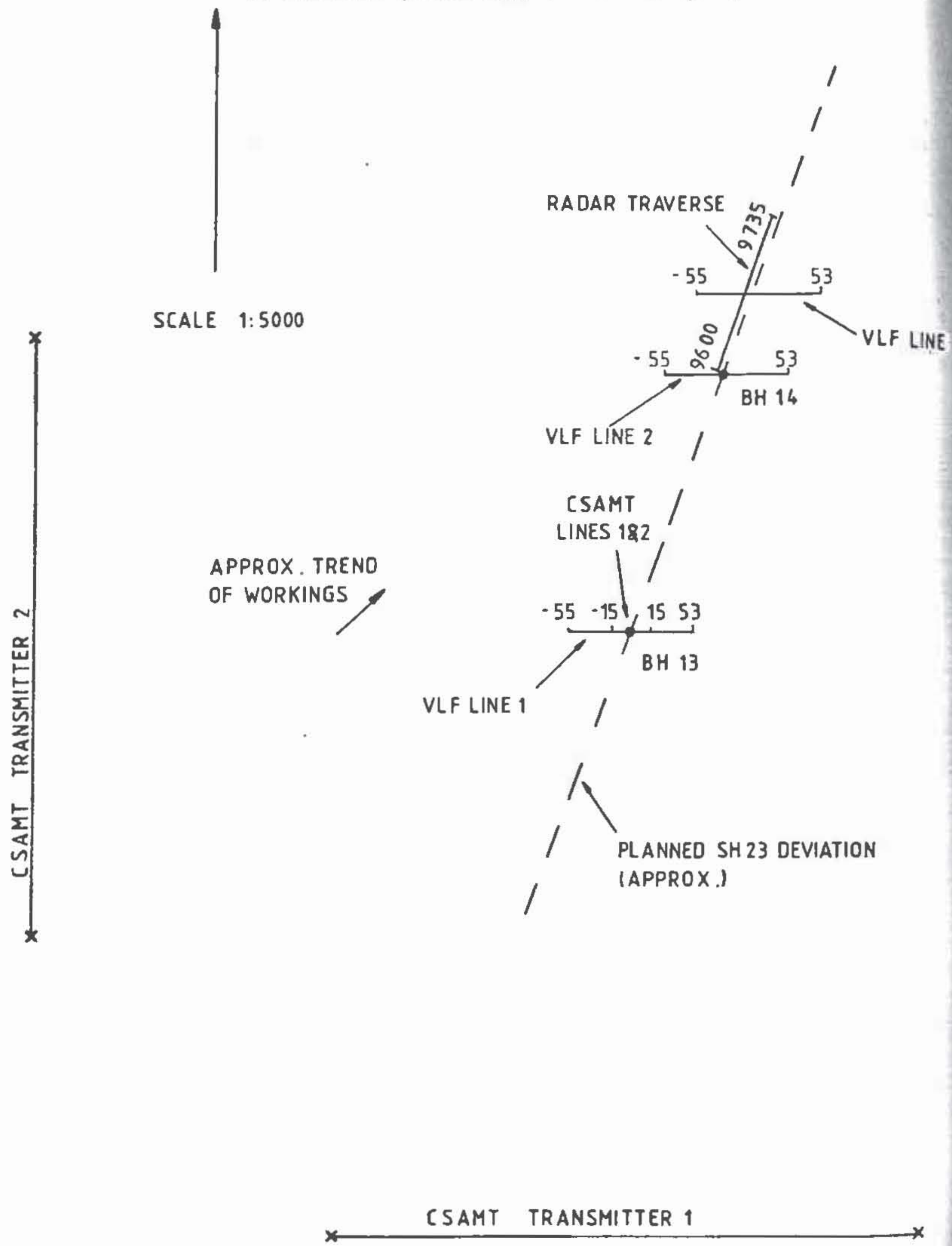

Figure 1. Site plan for ACIRL surveys. The RTA's SIROTEM, resistivity and VLF surveys were located around BH 14.

interpretation of the CSAMT data is that the resistive anomalies are due to remnant coal pillars. Between these are likely to be flooded voids.

GROUND RADAR SURVEY

Ground radar operates at much higher frequencies than VLF and CSAMT, typically in a range of 50 MHz to 250 MHz. At these frequencies, electromagnetic waves can be transmitted through most earth materials. Reflection surveys similar to those used in seismic exploration are possible. The wavelengths of the radar waves are very small when compared to seismic waves and high resolution imaging is possible. However, radar waves rapidly attenuate in the earth and penetration is limited.

It was recognised after a site inspection that ground conditions were not favourable for radar surveying. The soil in the area was both clayey and wet. As such it was highly conductive and would be a strong absorber of radar energy.

Nevertheless the trials were undertaken as planned. To improve antenna coupling and to reduce the likelihood of spurious above ground reflections from trees, a survey line was cleared by a bulldozer. The radar traverses were conducted over a 135 m length of this line (see Figure 1).

Traverses were made using 60 MHz and 120 MHz antennas. With the 60 MHz antennas, discrete data at 1 m intervals were recorded in digital form by an OYO Georadar I radar system. Continuous data were recorded using the 120 MHz antennas and an older OYO YL-R2 radar system.

As anticipated, the very high conductivity of the ground limited the penetration of the radar survey to about 3 to 4 m for both the 60 MHz and 120 MHz antennas. Consequently direct detection of voids was not possible.

DRILLING

At the time of writing, drill holes were being planned to confirm the predictions of the CSAMT survey and also to test the area in the vicinity of BH 14. On the CSAMT lines one hole is planned between the resistive zones where a void is interpreted to be present. It is hoped that results of the drilling will be available for reporting to the conference.

OTHER WORK

ACIRL's work on the detection of old workings is continuing. Further work using CSAMT, VLF and resistivity methods was undertaken at a mine site in the Bowen Basin late in 1989. Targets are air and water filled workings at depths between 20 and 40 m.

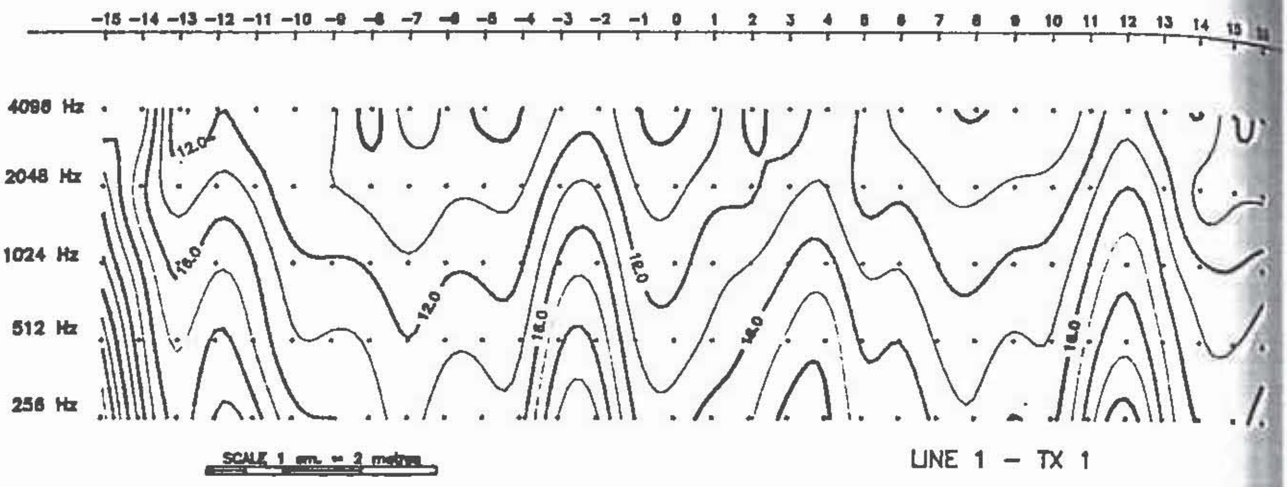

Figure 2. CSAMT Profile - resistivity vs frequency

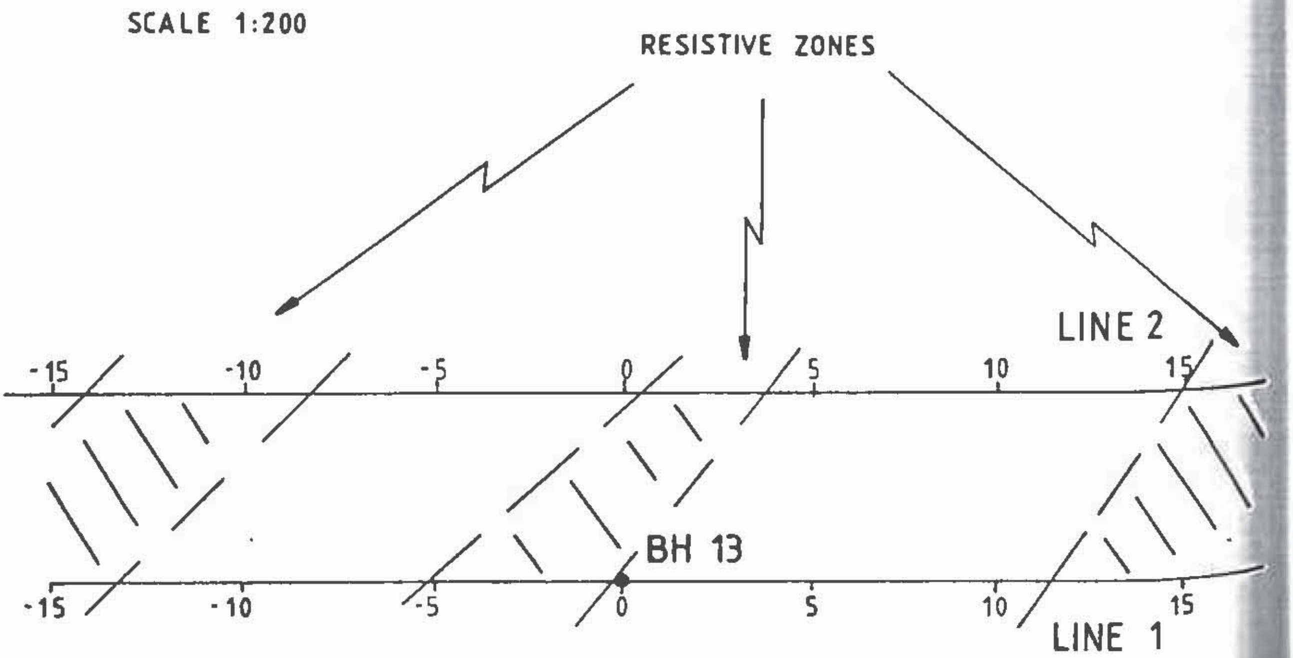

Figure 3. Trend of anomalous resistive zones, CSAMT lines 1 and 2

SOME GEOTECHNICAL PHENOMENA RELATED TO HIGH STRESSES IN THE HAWKESBURY SANDSTONE

J. BRAYBROOKE
D.J. Douglas & Partners

INTRODUCTION

Investigations for and monitoring of recent deep foundation excavations around Sydney are confirming the presence of near surface, high horizontal stresses in the Hawkesbury Sandstone. The monitoring is also recording differential movement of both the rock and engineering structures near the excavations.

Aiken (1964) appears to have been the first person to report differential movement along bedding and the sudden cracking of rock (particularly along lines of newly drilled blast holes) during excavation of Hawkesbury Sandstone. These movements were observed during construction of Warragamba Dam in the base of a 180 m deep V-shaped valley. Gray (1982) elaborated on some of Aiken's data, noting that in one (5.7 m deep) large diameter calyx hole differential movements occurred on all bedding planes with a maximum of 100 mm movement on one plane and an algebraic sum of movement of 230 mm. Gray also noted explosive cracking of some fine grained sandstone during excavation.

In the same paper Gray also noted that following excavation of the spillway channel at Woronora Dam, rock movements took place which crushed the bridge footings spanning the excavation. The cut was 50 m high and 25 mm of convergence occurred.

Similarly, there is hearsay evidence that about 25 mm of convergence also took place at Falcon Street Bridge abutments (North Sydney) during excavation of the Warringah Freeway (J. Muirhead, Consulting Structural Engineer, pers. com.).

More recently, during excavation of the 50 m deep Kangy Angy road cutting at Wyong, the Department of Main Roads, NSW, measured total movements of up to 400 mm of the west face in to the excavation and relative movements of up to 100 mm on shaly bedding planes within the Wyong Sandstone (Chappell et al, 1984).

Overcoring stress measurements were carried out which suggested a horizontal virgin stress of about 2.4 MPa at a depth of 50 m. A more recent review of the original measurements suggests that the horizontal, virgin stress may have been 1.4 MPa (about 1.2 times greater than overburden pressure) (Enever, 1985, pers. com.).

NEAR SURFACE IN SITU STRESS MEASUREMENTS

During investigations for the Water Board's ocean outfall tunnels the CSIRO carried out hydrofracturing stress measurements at depths of 70 to 124 m below the surface. These measurements indicated the maximum horizontal stress being 1.5 to 4.0 times (generally 2.0 to 2.5 times) greater than overburden pressure (Enever et al., 1984), that is, a Ko value of generally 2.0 - 2.5. This stress was oriented east of north.

In 1987 stress measurements were made at depths of 3 to 20 m in both the Mittagong Formation and the Hawkesbury Sandstone at the World Square site (near the corner of George and Liverpool Streets, Sydney) just after the start of bulk excavation. Two methods were used - overcoring of CSIRO cells by Dames and Moore and hydrofracturing by CSIRO. Both methods were carried out in vertical holes. Because of the presence of groundwater only two of the six overcoring tests tests were successful, while six of the 24 hydrofracture tests gave successful measurements of the horizontal stress field. These results have been plotted on Figure 1, together with many of the deeper stress measurements made around Sydney. As can be seen two of the World Square values are outliers. The near surface value was from a very stiff bed of fine grained sandstone in the Mittagong Formation. The other was from near the base of the excavation at the time and may represent a stress concentration effect at the wall/floor notch.

The World Square data can either be represented by a Ko of 3 to 4 or by the relationship $\sigma H = 0.5$ MPa + $2\sigma v$, where σH is the horizontal stress field and σv is the overburden pressure.

The stress field orientation results indicate that at the World Square site the major horizontal virgin stress direction lay slightly to the west of north (334° - 356°) rather than east of north as near the coast.

At the Liverpool Street end of the site, excavation was curtailed at a depth of 24 m. At this point 4 m of a 6 m thick, strong, sandstone bed had been excavated leaving 2 m of sandstone separated from the next underlying bed by a shaly bedding parting. Douglas and Partners measured the horizontal stress field at three points on this thin sandstone bed. The maximum stress was 4.0 to 5.1 MPa (between 6 and 10 tonnes greater than overburden pressure) with a different orientation at each location.

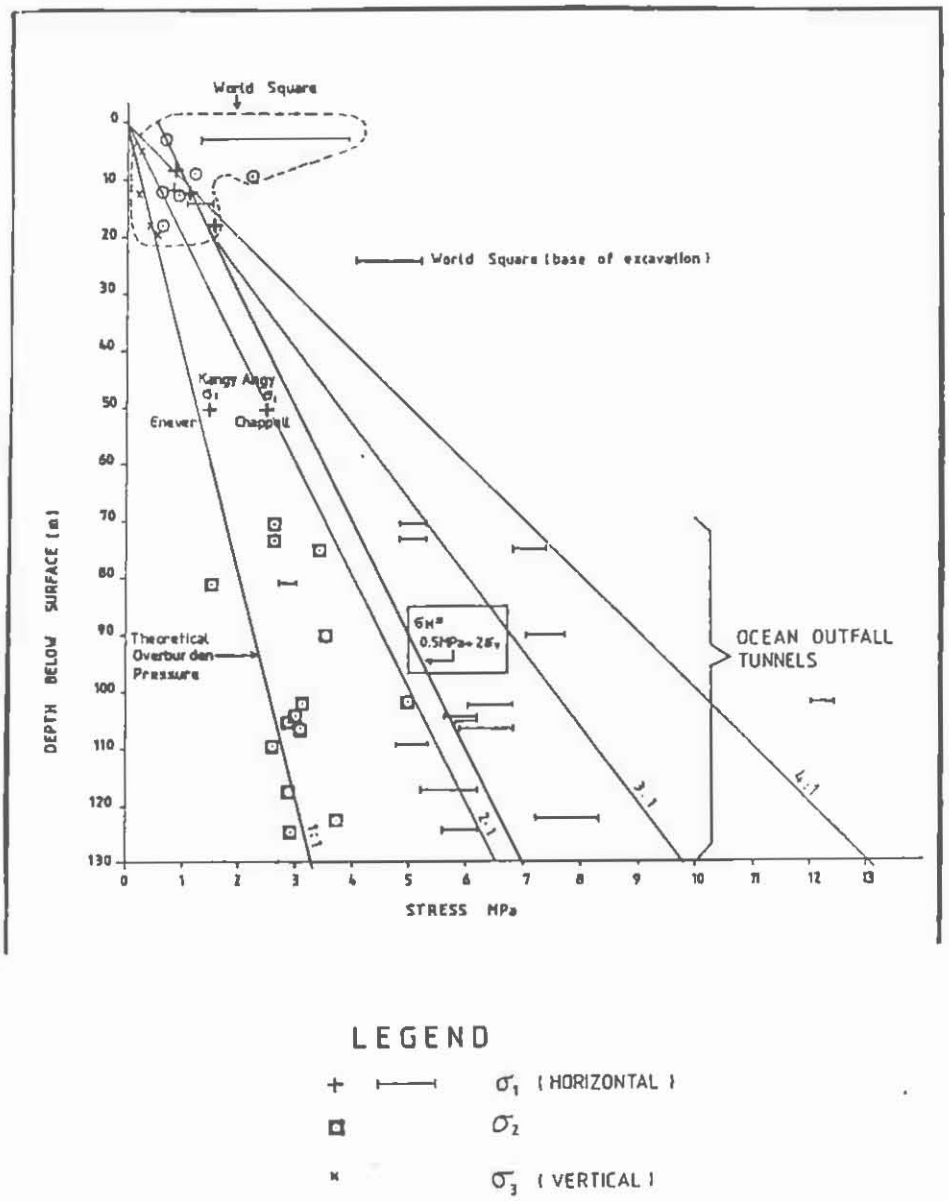

FIGURE 1. SUMMARY OF SYDNEY REGION NEAR SURFACE STRESS FIELD MEASUREMENTS

MODELLING OF ROCK MOVEMENTS

The World Square excavation is up to 28 m deep with a total of about 500,000 cubic metres of rock having been excavated. As the Eastern Suburbs Railway tunnels run along one side at about mid height of the excavation and within 8 to 12 m of the excavated face, there was some concern about the effect that movements induced by the excavation may have on the tunnel.

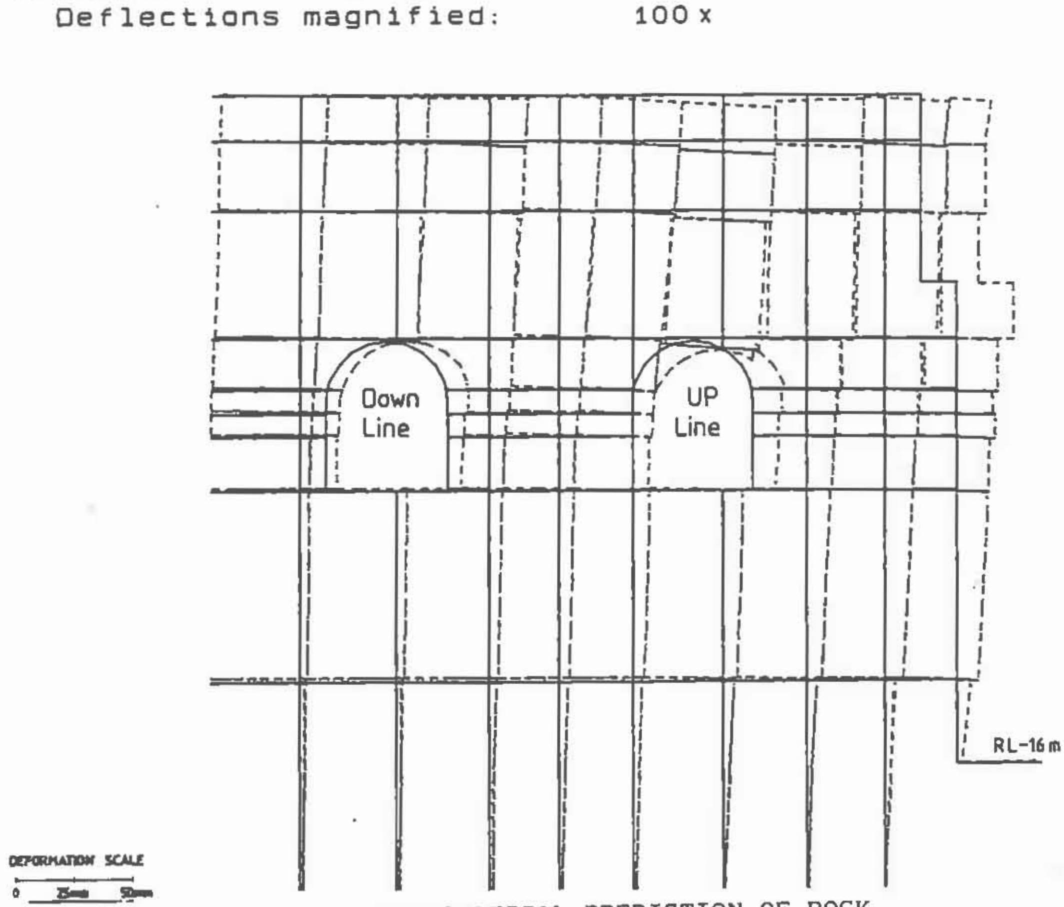

FIGURE 2. MATHEMATICAL PREDICTION OF ROCK MASS MOVEMENTS.

From geological mapping of the first part of the excavation, from geological logs of the tunnel made during construction and from realistic strength parameters for the rock, joints and shaly or clayey bedding planes a geotechnical model was produced. Using this model and the virgin stress field data, the movements shown on Figures 2 and 3 were mathematically predicted.

These predictions indicated that as excavation occurs the rockmass starts dilating as it is stress relieved. Because of the presence of weak, horizontal shaly bedding partings, this dilation has a step-like form with individual beds tending to act as struts until totally excavated. As excavation reduces bed thickness, the bed attracts more stress (cf. Douglas & Partners stress measurements) and compresses, allowing the rockface to move inwards along the underlying bedding plane. This occurs until equilibrium is reached between the residual stress in the bed and the shear strength of the bedding plane. With increasing depths of excavation the overlying beds are rafted outwards by dilation of the bed undergoing excavation.

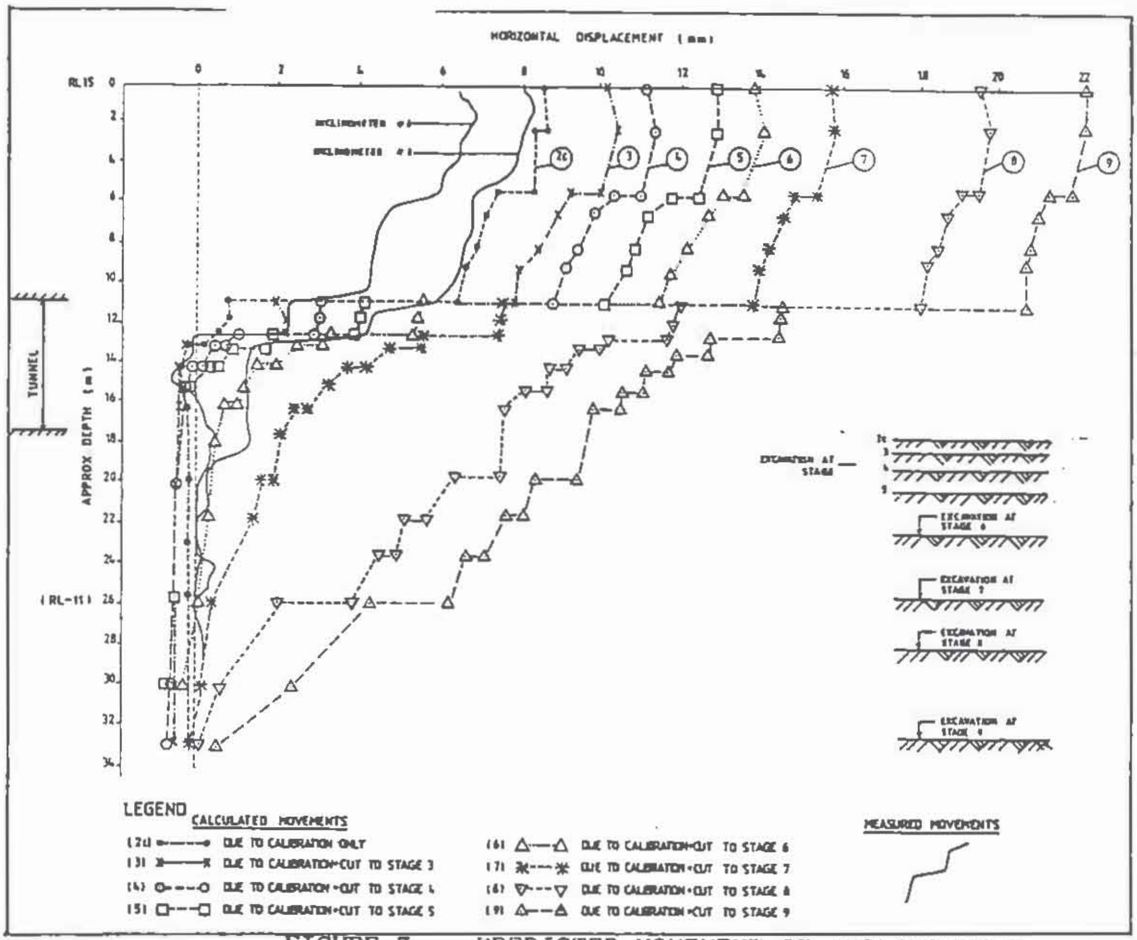

FIGURE 3. PREDICTED MOVEMENT OF INCLINOMETER 5 M BEHIND FACE

This rafting occurs providing that the overlying beds have little tensile strength, in other words, are jointed. As the beds are rafted the joints start opening behind the excavated face and any structures on or in the rock are also moved. The actual movement decreases away from the free face, but the total movement increases as the depth of excavation increases (Figure 4).

RECORDED ROCK MOVEMENTS

The rock movements predicted mathematically were borne out by the borehole inclinometer readings. These readings were taken by the SRA at four locations between the excavation face and the Up-line tunnel. At the same time other measurements were made including repeated surveys of the two tunnels.

These measurements showed that, opposite the centre of the excavation, the top of Inclinometer 3 (5 m behind the excavation) had moved some 30 mm while at tunnel level the inclinometer had moved 12 to 15 mm. The Down-line tunnel (almost 27 m behind the excavation) had moved about 5 mm towards the excavation.

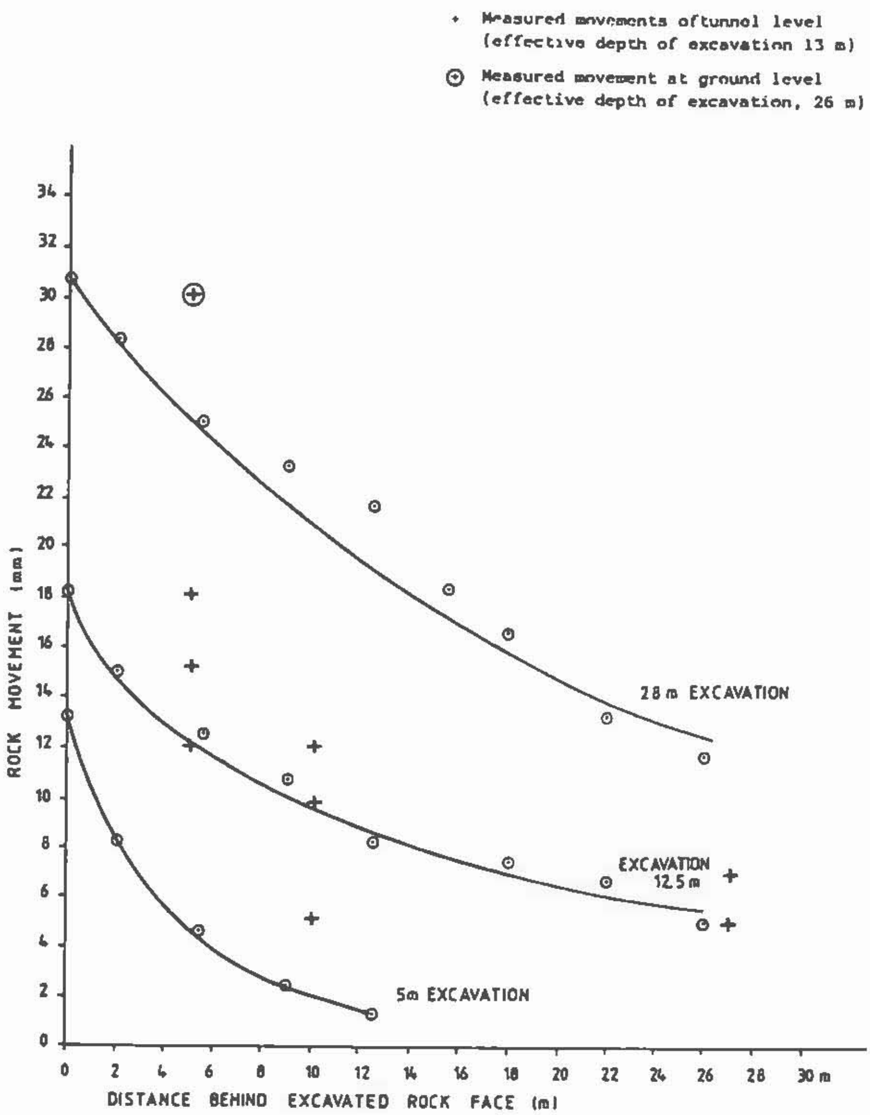

FIGURE 4. PREDICTED AND MEASURED ROCK MOVEMENTS vs DEPTH OF EXCAVATION

The tunnel lining showed shear cracking along what appeared to be the location of pre-existing joints which ran obliquely to the sides of the excavation. From extensometer readings taken across some of these cracks, and from load cells installed on some of the rock bolts (drilled across joints in the rock face) there were indications that individual joint blocks moved at different rates. It was this differential movement which caused shearing.

As would be expected, with an increase in length of the excavation, there was an increase in the total face movement. However, instead of the greatest movement taking place near the centre of the excavation, more movement was recorded towards the northern end. At a point 5 m behind the top of the excavated face this movement totalled about 45 mm. This asymetrical behaviour may have been due to the rock at the northern end of the excavation being closely jointed and thus less stiff than the rock at the southern end.

Other evidence of rock movement from sites around Sydney includes the development of drummy foundations in pad footings, particularly where the rock is thinly bedded; the development of new tensile cracks in the rock, particularly at re-entrant corners and, at a few sites, the incipient development of loose rock flakes. This flakiness has only been observed in strong, dense, fine or medium grained sandstone beds.

Where buildings are immediately alongside deep excavations the cracking of basement floor slabs of reinforced concrete buildings has been observed. This occurs both by opening of construction joints between slabs and by radial cracking of slabs where columns pass through them. Movement also shows up by the pulling apart of tie beams between columns.

In older brick and timber buildings it is often the architectural finishes which suffer, particularly with the development of diagonal cracks over doors and windows or cracking along beams. Some of this cracking is very similar to that induced by earthquakes or by the lateral spreading of foundations.

CONCLUSION

Apart from the obvious effects such movements have on engineering structures, the long term effects that downward cutting of rivers has had on geological structures also becomes more obvious. How many of you have wondered, as I have, why are some joint swarms apparently displaced consistently by bedding planes? Why are horizontal sheared seams so prevalent in some areas? and by what mechanism do vertical joints open near cliff edges?

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SOME NEWLY EXPOSED FAULTS IN THE SYDNEY REGION

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University of Sydney

INTRODUCTION

This paper discusses several interesting ,newly exposed or re-examined fault zones and thus continues the documentation of faulting in the Sydney region which began some thirteen years ago (Branagan, 1977; Moelle and Sutherland, 1977), and has continued in a series of papers (Norman and Branagan, 1984; Branagan, 1985; Norman, 1986; Branagan, Mills and Norman, 1987; Moelle and Branagan, 1988; Mills, Moelle and Branagan, 1989;).

Although considerable progress has been made in the mapping of the faults we are not yet in a position to attempt a final synthesis of the data as the distribution of the structures studied is still rather patchy.

As indicated in the previous papers, normal faults, high -angle reverse faults, low-angle thrusts, and strike-slip faults all occur in the region. Those studied to date are shown on Figure 1.

Figure 2 shows the location of three localities on the Hornsby Plateau where faults are exposed. Each of these sites is described below.

BOBBIN HEAD ROAD

This site is described in part by Norman (1986). It lies in a north-south (magnetic) trending zone which is dominated by a strong normal fault zone in which the horizontal Hawkesbury Sandstone beds have been dragged down to dip 60° westwards on the main fault (Figure 3). A subsidiary, steeply east dipping and normal antithetic fault, a few metres to the west of the main fault plane, allows a centre block to be downfaulted (see Figure 3). In the adjacent rocks (i.e. within 100 metres) there are signs of other types of deformation, e.g. brecciation (on both vertical and sub-horizontal surfaces), thrusting, dyke intrusion and horizontal strike slip on steep joint planes striking 205° and 072° (magnetic). However we believe the normal extensional faulting is the dominant type of deformation at this site. The severe down-dragging of the beds marks the site as being somewhat more intensely faulted than usually recorded in the region. The faulting has been traced only about 50 metres and there is no indication of an extensive zone to the south, but Norman (op cit) suggests a total length to the north of 500 metres.

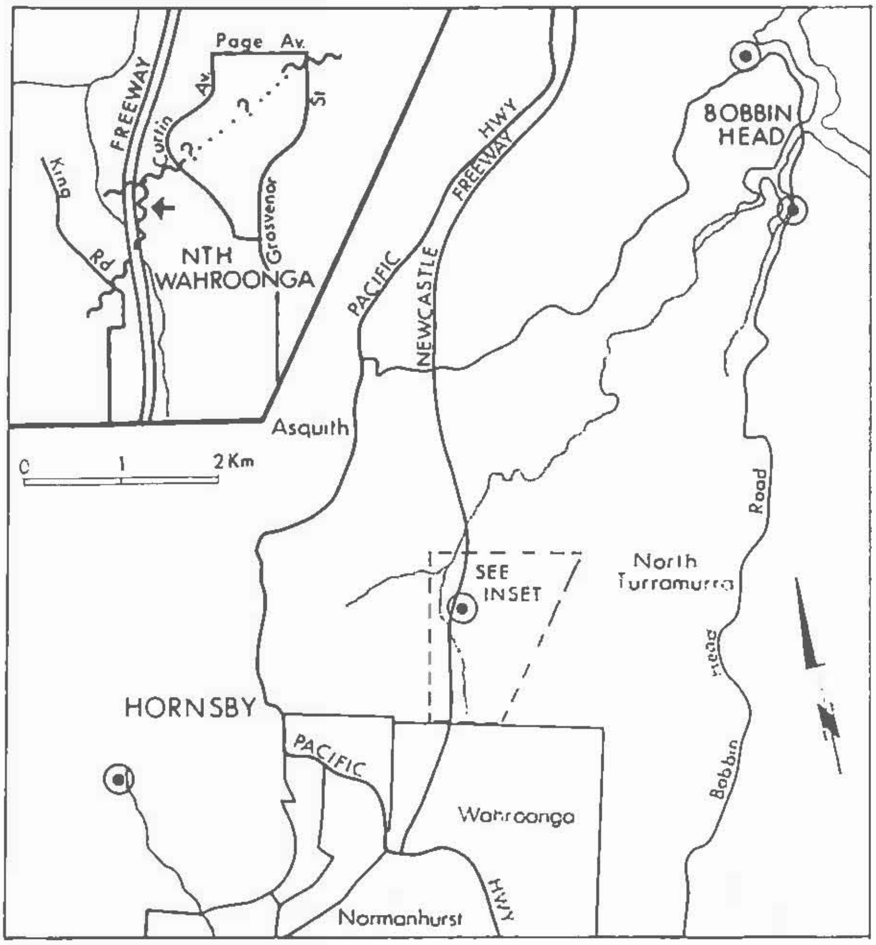

Figure 2. Three fault zone sites on the Hornsby Plateau.
Figure 2a. Inset. Thrust zone locality near Hornsby.

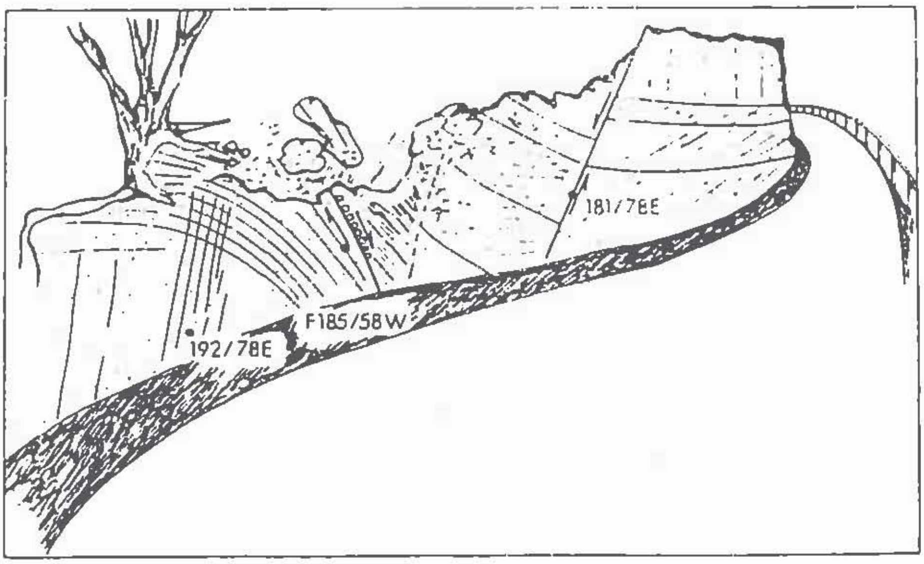

Figure 3. Cross-section of south trending fault zone, Bobbin Head.

separate sandstone from black shale within the Hawkesbury Sandstone. The faults strike a little west of north-south (190^{o} to 202^{o} degrees,mag.) and dip easterly, the inclination varying between 60^{o} and 85^{o} degrees.Within the fault zone The beds themselves are tilted to a maximum dip of up to 85^{o} .Slickenlines are well-defined on many faces, pitching southerly at 85^{o}. In one place shale containing thin sandstone layers is overturned at the contact beneath a fault plane. The fault zone is exposed along a distance of nearly 100 metres,.and is broadly expressed by an apparent fold when viewed from a distance of some 50 metres, i.e. the northbound carriageway.

However the fault zone may be more extensive. A similar structure was recorded to the south west about 500 metres in Spring Gully Place off Kings Road Hornsby where the dip was 70 degrees (Branagan, 1985).

The thrust in the expressway cutting is interrupted by a normal fault striking 070 degrees (mag.) and dipping 85 degrees to the north. This fault is about 5 centimetres wide and contains a breccia of black shale. The displacement of the normal fault is probably less than a few metres. A possible extension of this normal fault occurs in Grosvenor Street, North Wahroonga, some 1500 metres to the east.of the expressway (Figure 2a).

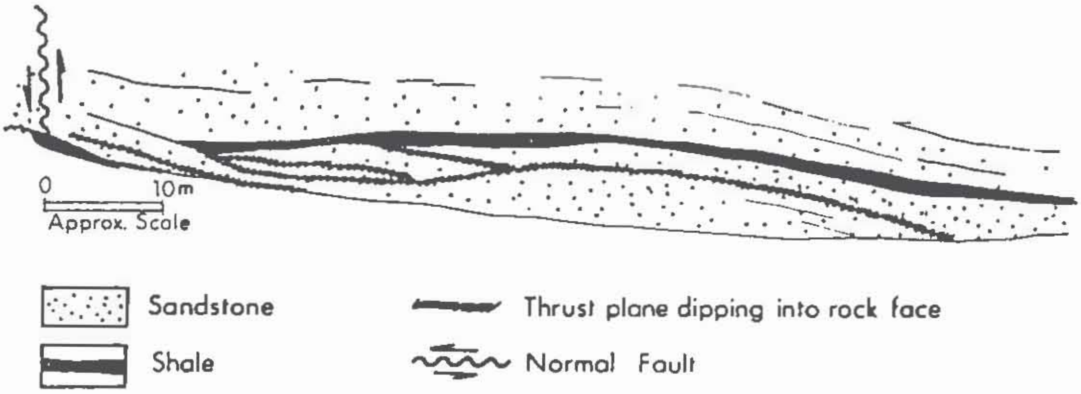

Figure 4. Road section exposing thrust zone on Newcastle Freeway, Hornsby.

NORMAN STREET, NORMANHURST

This locality was referred to by Branagan (1985), and one feature, strongly developed horizontal slickensides, with evidence of sinistral movement, was recorded,. The vertical fault on which this occurs strikes 072^{o}. Nearby (ten metres to the northwest.) several thrust planes strike north-south and dip west at up to 30 degrees. These thrusts consist of brecciated sandstone zones up to 6 centimetres thick cutting through massive sandstone. and through occasional shale and shale breccia layers. A normal fault,striking 018^{o} degrees(mag.) and dipping 75^{o} west, is also present.

NEW SYDNEY FAULTS

GENERAL COMMENTS

The types of failure recorded at these three localities epitomise the deformation which has occurred throughout the Hornsby Plateau, but the intensity is possibly greater than usual. However no consistent story can yet be made to explain the features. While thrusting appears to have been dominantly from the east there has also been thrusting from the west, and no time sequence can as yet be established. In fact the evidence is apparently contradictory at times, e.g. the movements on strike -slip faults is not consistently in one direction, and the relative age of thrusting to normal faulting is also different at different localities. For instance the easterly striking normal faulting in the Hornsby cutting clearly post-dates the thrusting, a relationship that is not clear at Mooney where Mills et al (1989), on the basis of overprinting, suggest that the high angle faults are older.

While there is a wide range in orientation of the horizontally slickensided faults they all are related to the broadly east-west set of structures, and are the result of a dominantly east-west shear couple component, with the sole exception of a questionable occurrence in a dyke on the coast at the south end of Palm Beach, where the trend is northeast. On the other hand the various north-south fracture zones show no evidence of strike-slip movement.

As is to be expected, dyke intrusion is common in the fracture zones, occurring more frequently in east-west structures. Evidence at Norah Head suggests that of the two intersecting dykes found there the north trending one came later, but the time difference may have been slight.

The role of broad fold structures, such as the Dural Anticline, in controlling the block displacements has yet to be assessed, but further data on the distribution of the various faults are still also required. It seems likely that the thin-skin tectonics in the Hunter Coalfield (Glen and Beckett, 1989) is significant further to the south in the Sydney Basin.

WORONORA PLATEAU

This section deals briefly with several structures exposed along the F5 Freeway near Mittagong and Berrima (Figure 1). Reference was made by Moelle and Branagan(1988) to thrusting in Ashfield Shale south of Berrima, the implication being that such structures indicated continuation of the Hunter-Bowen deformation till middle Triassic or later, and effective well to the south end of the Sydney Basin.

While such structures exist on the plateau, (e.g. near Loftus) detailed examination of those exposed on Freeway 5 shows their formation seems to be related essentially to local causes, viz. the intrusion of a variety of igneous bodies. Eight kilometres north of Mittagong several thin sills are exposed in road cuttings. These are broken up by a series of 'transfer' faults which move the sills to different levels. These faults are akin to transform faults in that they die out in both directions (horizontally and vertically) , (Figure 5) .

Near Bendooley Hill, road cuttings, on both sides of the freeway show extensive faulting (Figure 6). The various structures are the result of breccia intrusion. The breccia is confined largely to the eastern side of the expressway and is part of a diatreme, some 500 metres in diameter, which occurs east of the Freeway. The curious sag structure in the centre of the western face is the result of withdrawal of support as the igneous material

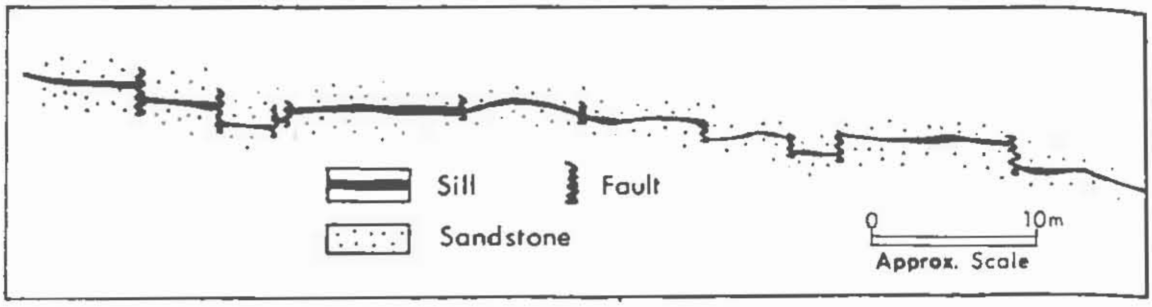

Figure 5. Transfer faults displacing sill intrusion, F5 Freeway north of Mittagong.

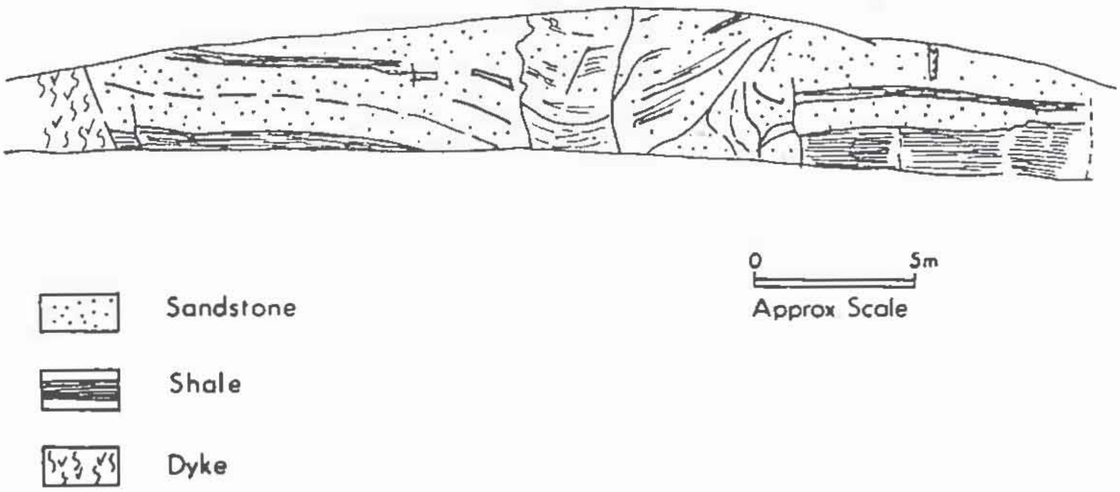

Figure 6. 'Collapse' fault zone and normal faults, F5 Freeway near Berrima.

cooled. Careful examination of the grey rock exposed in many of the cuttings in this vicinity is required, as one is inclined to assume it is all Ashfield Shale. However some of this layered rock proves to be breccia which has faulted contacts with shale or, at times, with sandstone.

DISCUSSION

Many of the faults exposed on the F5 Freeway are caused by igneous intrusions. This contrasts with the faulting on the Hornsby Plateau which predates igneous intrusion, and forms the locus for emplacement. Whether this is a fundamental difference between the plateaux remains to be seen, but it reinforces the idea that the tectonic histories of the two parts of the Sydney Basin are distinct to some degree at least.

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ACKNOWLEDGEMENTS

The diagrams for this paper were kindly prepared at short notice by Brenda Durie, Department of Geology and Geophysics, The University of Sydney.

THE 1989 NEWCASTLE EARTHQUAKE AND THE SEISMICITY OF THE SYDNEY BASIN

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The Newcastle earthquake of 28 December 1989 was the first earthquake in Australia known to have caused loss of life. Twelve people were killed and an estimated \$1.5 billion damage resulted from the ML 5.6 earthquake. It finally put to rest the myth that Australia is a stable aseismic continent.

The earthquake hypocentral parameters of the earthquake are:

Origin time	23h 26m 58s UTC
Latitude	32.95($\pm$ 0.06)^{o}S
Longitude	151.61($\pm$ 0.16)^{o}E
Focal Depth	11.5($\pm$ 0.5)km

Only one aftershock (ML 2.1) large enough to be located was detected by a local network that was installed in the Newcastle region within 12 hours of the main shock. It had a depth of 14($\pm$1)km and an epicentre similar to that of the main earthquake. The lack of aftershocks is unusual. Both the 1961 Robertson and 1973 Picton earthquakes, which took place in the southern part of the basin, and were of similar size to the 1989 Newcastle earthquake, generated many aftershocks.

Focal mechanisms

The absence of aftershocks makes it difficult to determine the extent of the fault plane, but a focal mechanism based mainly on first motion data from regional seismographs indicates a thrust mechanism. The fault strikes 105 degrees and dips to the southwest at 32 degrees. The pressure axis strikes 44 degrees and dips 10 degrees. This mechanism is similar to those for the 1961 Robertson and 1973 Picton earthquakes. The table below summarises the pressure directions for six earthquakes that have occurred beneath the Sydney Basin in recent years.

Table 1 summary of focal parameters - Sydney Basin earthquakes

EARTHQUAKE	DATE	LOCATION LAT°S	LONG°E	MAGNITUDE Ml	PRESSURE AXIS TREND PLUNGE
Robertson	21 May 1961	34.55	150.50	5.6	46, 34
Picton	29 May 1973	34.17	150.32	5.5	64, 06
Appin	15 Nov 1981	34.25	150.90	4.6	275, 03* (95)
Lithgow	13 Feb 1985	33.49	150.18	4.3	114, 06*
*Lithgow	24 Jun 1987	33.43	150.15	4.3	37, 14* (94, 32)
Newcastle	28 Dec 1989	32.95	151.61	5.6	44, 10

* Unreliable solution

The pressure axes from these earthquakes are almost orthogonal to those obtained from earthquakes that have occurred in the Lachlan Fold belt to the southwest.

Historical earthquakes

The 1989 Newcastle earthquake is not the first earthquake to have damaged buildings in the Sydney Basin region. Both the Robertson and Picton earthquakes caused approximately $0.5M damage in 1961 and 1973 dollar values, and the 1985 Lithgow earthquake caused $65k damage. Earlier earthquakes such as the 1919 Kurrajong and the June 1868 and December 1925 events near Newcastle caused negligible damage. The 1868 and 1925 earthquakes took place close to the 1989 earthquake but were not as large (ML=5.3 and 5.1 respectively).

The 1989 earthquake felt over an equivalent area of 300,000km^2. Most of the damage was concentrated on the estuarine alluvial deposits in the Newcastle central business district approximately 12km north of the epicentre.

Implications for building codes

The Newcastle earthquake has highlighted the risk of earthquake damage in the Sydney Basin and the requirement to re-assess the current building codes. The 1979 code put Newcastle in Zone 0, but the revision completed by Gaull, Leiba and Rynn in 1988 includes Newcastle in Zone A. Clearly there is a need to improve the monitoring of the Hunter Valley region to identify active fault zones and to install a network of strong ground motion recorders in urban areas for input to engineering designs.

No longer will Australia be regarded as the stable aseismic continent where earthquakes do not attack.

THE NEWCASTLE EARTHQUAKE - OBSERVATIONS FROM THE QUEENSLAND GOVERNMENT TASK FORCE

J. Hopgood
Senior Sergeant, Operational Planning Unit,
Queensland Police

The State of Queensland proudly maintains an emergency services operation that utilises many State services in the aftermath of a natural disaster. It is an essential service for Queensland because cyclones and floods are annual occurrences. Queensland has not had the experience that befell Newcastle on 28th December, 1989.

We were invited as observers to the post-earthquake situation and our aim was to gain first hand experience so that our emergency services will be fully equipped to handle such an event if it occurs in the future. We acknowledge the support and assistance since 29th December, 1989 of Alderman John McNaughton, Lord Mayor of the City of Newcastle, Chief Superintendent Russell Cook, Inspector Terry Collins, Detective Sergeant Eddie Riggs and all officers of the Department, the Newcastle Fire Brigade, NSW State Emergency Service, NSW Ambulance Service and the many citizens of Newcastle and its environs. Our task force comprised:

John Hopgood: Senior Sergeant, Operational; Planning Unit, Queensland Police

Keith Drummond, Chief Officer, Metropolitan Fire Brigade, Brisbane

Lana Bickford, Assistant Director, State Emergency Services, Brisbane

Paul Scow, Formerly Medical Director (Southern Area), Department of Health, Brisbane

Jack Rynn, Research Fellow in Seismology, University of Queensland

The task force was organised by Mr. N. Newnham, Police Commissioner for Queensland at the direction of the Minister for Police and Emergency Services, the Hon. T. Mackinnoth, MLA. The logistical operations were under the direction of the Police Commissioner for NSW. We arrived in Newcastle on the morning of Friday 29th December, 1989 and departed on Sunday 31st December, 1989.

The brief of the task force was to assist the Newcastle services through practical advice based on our experiences of disasters in Queensland. In this context our operations included:

* observation of the responses

* noting procedures in the immediate post earthquake phase by rescue organisations

* noting the role of support organisations

* discussions and briefings with the police, fire services, ambulance service, SES, Royal Newcastle Hospital, the Lord Mayor and trauma/welfare workers

* first hand observation of emergency services and facilities within Newcastle

The initial visit was followed a week later by a technical team under Dr Jack Rynn (University of Queensland). This team collected observational data and initiated the felt report collection of data.

A further visit about a week later by Dr J. Rynn and Mr E. Brennan followed up this seismological-engineering data program and began to investigate the geological conditions pertaining to the earthquake.

The official earthquake debriefing on Thursday 1 February 1990 was attended by the Task Force through an invitation of the Lord Mayor of Newcastle. Several of the technical team then attended The Institution of Engineers, Australia, Symposium on 15-17 February, 1990.

The situation at present involves the collection, collation and analysis of all data, both from the emergency services and technical viewpoints. The results will then be disseminated in the form of reports and scientific papers to all interested persons in the community.

ENGINEERING GEOLOGICAL CONSIDERATIONS SUBSEQUENT TO THE NEWCASTLE EARTHQUAKE

G. DEAN-JONES[1], D.F. BRANAGAN[2] & K.H.R. MOELLE[1]

[1] University of Newcastle

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EARLY RECORDS

It is not uncommon for earthquakes to be experienced in the Sydney Basin. Tremors were recorded shortly after the arrival of the First Fleet, but because there were no substantial buildings, no significant damage was recorded. George Caley made more sophisticated observations on an earthquake on the 12th February 1801. He noted the direction of movement of the surface wave: "it came from the east and proceeded to the west fortunately no further damage was done than a few houses a little shattered had the like happened in England buildings would have been very much shattered and many thrown down."

On the 3rd August 1837, the Reverend C.P.N. Wilton recorded a tremor at Newcastle, N.S.W. which, he noted, was felt strongly on the beacon cliff "but was not felt in the coal mines, twenty fathoms below the surface." The Reverend W.B. Clarke noted a similar occurrence at Newcastle on the 18th June 1868, but was somewhat sceptical of labourers working on the wharf, "who declare they felt nothing of the shock whatever," remarking that "it may be said they were so occupied as not to distinguish the motion." Clarke recorded a number of tremors, including one in 1841.

Clarke noted that the 1841 tremor emanated from the Maitland region "determined in a way that could not deceive, by an observation on the soap-suds thrown up in the hand-basin in the room, and which is the next best indication to that of treacle." He felt that the earthquake on 18th June 1868 came from the same direction, and stated that "unquestionably it was felt more violently about the lower Hunter than elsewhere, and the heaving of the earth was distinctly perceived at Newcastle and Raymond Terrace."

D.F. BRANAGAN, G. DEAN-JONES & K.H.R. MOELLE

THE 1925 NEWCASTLE EARTHQUAKE

The strong earthquake which occurred in Newcastle on the 19th December 1925, with a Modified Mercalli intensity of around VI, caused panic among a theatre audience, but there was apparently little structural damage. At first some people believed that the movement resulted from the collapse of pillars in the old mines beneath the city. This tremor was felt quite strongly in the Sydney region, but many people attributed it to explosions associated with the construction of the Harbour Bridge. Dr Pigot, of Riverview Observatory, placed the epicentre on the continental shelf not far east of Newcastle.

Although several articles appeared over the next few days, the earthquake, stronger than the Kurrajong 'quake of 1919, was soon almost forgotten, "scientific opinion" being that "there was no ground for alarm at this occurrence, or in regard to future shocks, as they are very rare, and it is added, by no means serious."

GEOLOGICAL BACKGROUND

The great variety of rocktypes in the Newcastle Coal Measure sequence has significant implications for engineering works, as rocks with very different mechanical properties occur in a layered succession. In addition to this layered anisotropy, nests of faults and swarms of dykes represent several phases of brittle deformation and emplacement of igneous material.

The faults with appreciable displacements (>1 metre) trend predominantly NW-SE; a smaller number has NNW-SSE and NS strike trends. Most faults are normal faults with dips to the southwest or west. The few existing reverse faults dip toward the northeast.

The dykes consist of olivine dolerite and trend, in a NW-SE or, to a lesser extent in a NNE-SSW attitude. The majority of dykes thus parallel the major faults and joint systems.

Most faults and dykes are either vertical or dip steeply (80° to vertical); some reverse faults have low dip values, and there is some evidence that bedding plane fault movements have occurred. Consequently the rockmasses of the Newcastle Coal Measures have been subjected to extensional and to shortening phases of regional deformation. Joint systems and slickensided surfaces have been used to reconstruct stress directions (Gale, 1980); significant changes in the attitudes and magnitudes of principal stresses have been determined. The presently active maximum principal stress has been measured to range between N45°E and EW, with a slight inclination to the west. The magnitudes measured vary considerably from approximately 4.0 MPa to 10.7 MPa, with the high stresses found at very shallow depths.

ENGINEERING GEOLOGICAL CONSIDERATIONS, NEWCASTLE EARTHQUAKE

The occurrence of high lateral stresses in upper Permian and lower Triassic sandstones at shallow depth (approximately 45 to 55 metres) is a significant feature in the context of seismic events and their analysis. The ratio of vertical to horizontal pressures has been determined in the operating collieries as being V:H = 1:2 or, in some localities, even as V:H = 1:2.7. The presence of a relatively large number of faults in the Macquarie Syncline with parallel trends to large faults in the basement is likely to provide a favourable geological setting for the release of stored strain energy.

The propagation of the seismic waves occurs in a multilayer medium (the Newcastle Coal Measure sequence) with layered half spaces as defined by the nests of faults, the swarms of dykes and the surface. The situation is further complicated by the presence of solid layers with very different properties and solid half spaces with identical or very similar properties which all influence the propagation of waves. The principal conclusions for surface waves may be obtained directly from the characteristic relation between period and phase velocity, which is probably identical for each physical system. The duration and the complexity of the earthquake waves recorded are the main targets of our future research efforts.

The reflected and refracted waves in the layered medium can be calculated for the major lithological units, as they impinge upon solid interfaces of near-horizontal disposition, whereas the dykes and faults add vertical solid interfaces to the configuration of the rockmass in which the waves propagate. The existing abandoned mine workings on at least one horizontal level, sometimes on two levels, probably play a major role in the dissipation of energy, as has been demonstrated during the Newcastle Harbour Deepening Project.

The great lithological diversity of the Newcastle Coal Measure sequence and the high order of mechanical anisotropy require also the consideration of damping of elastic waves resulting from imperfections in elasticity, especially from "internal friction," consequently an elastic constant like μ may have to be replaced by

$$\mu + \mu' \frac{d}{dt} \tag{1}$$

in the equations of motion. The stress thus becomes a linear function of both the strain and the time rate of strain change.

The boundary conditions in this complex succession of sedimentary units will most probably require the addition of some special conditions, as they express the behaviour of stresses and displacement at the boundaries.

Although much damage in the Newcastle area seems sporadic with failures directly attributable to structures being unable to resist lateral forces, the occurrence of particular "damage centres" and "damage patterns" in the City of

Newcastle area can in some instances be explained by geological features. The presence of fluvially deposited sands in old river beds of the large Hunter River estuary may have contributed to certain damage patterns and centres in Hamilton and The Junction, which are founded on unconsolidated alluvium. The distribution of underground workings and unmined areas, some in the form of barrier pillars separating individual collieries, appears to have contributed to the occurrence of what might be called 'site specific' damage clusters.

The possible relationships should now be tested and defined by detailed mapping, involving also drilling, damage analysis and cause-effect analyses.

CHANGES IN THINKING

The possibility of damage on a significant scale from earthquakes in the Sydney Basin region seems to have become a consideration only in the 1960s following the Robertson shake of the 21st May 1961, which had a Richter magnitude of 5.8. This led to some recommendations for changes to the building codes, but no legally binding rules seem to have been established (Standards Association, 1979).

The Newcastle earthquake sets an Australian precedent for a seismic event of significant magnitude affecting an urbanized area producing intensities ranking amongst the highest recorded in the eastern part of the continent. This earthquake at Newcastle is also notable for the variety of opinions given by scientists as to the cause of the movements, as well as for the disagreements about the need or the economic sense for introducing rigid building codes which would either prevent or drastically reduce structural damage.

Most observers agree, however, that earthquakes of an magnitude up to 6.0 on the Richter scale will continue to occur in the Sydney Basin. The Newcastle region seems to have been directly affected on an average of about once in 60 years, but the frequency interval within the Sydney Basin is somewhat less. Branagan (1985) pointed out that there seemed to be an interesting space/time pattern in the variation of the epicentral positions of earthquakes, swinging from beneath the Sydney Basin to outside (west) and then back, and that records showed a noticeably reduced time interval towards the present time (Fig. 1).

CONCLUSION

In addition to the need to set up more seismic stations, we need to carry out considerably more systematic measurements of stress directions and magnitudes (σ_1, σ_2 and σ_3) in order to ascertain which areas and rockmasses are being affected, and to what degree.

ENGINEERING GEOLOGICAL CONSIDERATIONS, NEWCASTLE EARTHQUAKE

The disagreements concerning the specific causes of particular earthquakes demonstrate that we are a long way from being able to predict the focus or the intensity of earthquakes. Scientists can, however, contribute to the establishment of appropriate design criteria for foundations and other engineering structures in areas which can obviously no longer be classed as zone zero.

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EARTHQUAKE RISK IN EASTERN AUSTRALIA - LESSONS FROM NEWCASTLE

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INTRODUCTION

Earthquakes are a reality on the Australian continent. Unfortunately, it has taken the fatal and disastrous 1989 Newcastle earthquake to shock Australia into the realisation that we are not immune from the most devastating natural disaster known to man - an earthquake. It has reminded the world that earthquakes do not occur just at plate margins (eg Japan, New Zealand, South America) but that some earthquakes occur within plates (eg China). All continental masses are prone to the occurrence of earthquakes and the resultant potential devastation to life, property and industry and this risk must be included in the nation's disaster management programs.

The belief of many Australian citizens and politicians that "Australia is a stable continent - we do not have earthquakes" is totally invalid. Australia has had large (eg 1988 Tennant Creek) and disastrous earthquakes (eg 1918 Queensland, 1954 Adelaide, 1968 Meckering, 1973 Picton). The effects of these earthquakes has either gone totally unnoticed or has only been remembered by those who lived in the immediate vicinity of the epicentres. It has had to take the fatal Newcastle earthquake to emphasise that our solid Earth is dynamic. Such past ignorance must be put to rest forever.

The earthquake hazard is always present, particularly for eastern Australia. As such, there exists a real and quantifiable earthquake risk that now must be given serious priority in scientific and seismological research in Australia.

LESSONS FROM THE NEWCASTLE EARTHQUAKE

Over the last 5 years, the University of Queensland "Working Group in Earthquake Engineering" has been actively engaged in a program of multidisciplinary research in the earthquake hazard of northeastern Australia (Queensland and NE NSW). The many disciplines of seismology, geology, engineering, insurance, architecture and emergency services have been integrated into the quantification of the potential earthquake risk in our continental regime (Rynn 1989). Such information has been disseminated through four engineering workshops, directed primarily at the engineering and insurance communities.

While the data pertains to NE Australia, the many results of earthquake research in Australia and other continental areas (particularly central and eastern USA) have been closely studied. The 1989 Newcastle earthquake provided the "on-the-ground" opportunity to implement many aspects of the research through the Queensland Government Task Force (Hopgood, 1990; 24th Newcastle Symposium) in co-operation with the Lord Mayor of Newcastle and the Newcastle Police District.

It is clearly evident that there is a wealth of data available in all disciplines. With these data, the earthquake risk for continental regimes can be assessed. The results of such research can be integrated through all the technological and sociological avenues of disaster management.

The brief of our program is simple - provide the necessary and sufficient information that will benefit the future welfare of all Australians by saving human life and mitigating property damage in the event of a future damaging earthquake.

SEISMOLOGY

Focal parameters

A preliminary determination of the focal parameters for the 1989 Newcastle earthquake was reported by the Australian Seismology Centre of the Bureau of Mineral Resources (ASC/BMR) at the Institution of Engineers, Australia "Conference on the Newcastle Earthquake", 15-17 February, 1990 (McCue et al. 1990).

Origin time:	28th December, 1989 23:26:58 hours UTC (10.27am local time)
Epicentre:	32.95°S, 151.61°E (near Boolaroo, approximately 15km WSW of the Newcastle Central Business District).
Focal depth:	12km
Richter magnitude:	ML 5.6

These data were derived from both local and overseas data. Of interest is the focal depth. A seismogram from a station in Scotland (approximately 150° distant) clearly recorded a surface reflected P wave which allowed a focal depth to be computed.

Two other determinations of focal parameters are available:

(1) Research School of Earth Sciences, Australian National University

Origin time:	28th December, 23:26:56.7 hours UTC
Epicentre:	33.01°S, 151.78°E (on the coast near Newcastle Beach, just to the east of the Central Business District)
Focal depth:	8km
Richter magnitude:	MD 5.0

(2) US Geological Survey (from world wide data)

Origin time:	28th December, 1989 23:26:56.7 hours UTC
Epicentre:	32.95°S, 151.64°E
Focal depth:	10km
Duration magnitude:	MD 5.5

All determinations, with their respective errors, place the epicentre within a 10-15 km error ellipse of the Newcastle central business district.

Aftershocks

One aftershock was measured by the portable seismograph array employed immediately after the main shock (McCue et al. 1990). This occurred on Friday 29th December, 1989 at 7.08pm.

Origin time:	29th December, 1989 09:08:09.6 hours UTC
Epicentre:	32.95°S, 151.62°E
Focal depth:	13.6 km
Richter magnitude:	ML 2.1

The effects of the aftershock were felt by many in the Newcastle area. No additional damage was reported from this event.

Geological conditions

The 1989 Newcastle earthquake is a continental (or intra-plate) earthquake. It occurred in the northern part of the Sydney Basin, south of the complex Hunter-Mooki thrust system. Some preliminary considerations given at the Institution of Engineers, Australia Symposium associate this event with the axis of the Macquarie Syncline (K. Moelle, pers. comm. 1990).

Previous earthquakes in the Newcastle area

At least ten earthquakes have had their effects felt in the Newcastle area since 1820 (C. Hunter, pers. comm. 1990). Of note are the 1868 Maitland and 1925 Boolaroo earthquakes which caused structural damage to buildings. Some of the other eight earthquakes were probably centred in the lower Hunter Valley. The area has a seismic history recorded in some of the earlier studies of the Sydney Basin (Doyle et al. 1968, Drake 1974) and current seismic monitoring by the Australian National University (B. Kennett, pers. comm. 1990). These studies show that the area has a few earthquakes of Richter magnitude ML $<$ 4 per year.

EARTHQUAKE ENGINEERING DETAILS

Felt effects

The effects of the 1989 Newcastle earthquake have been felt over an area of more than 200,000 km^2. This covers an area from south of Canberra, west of Dubbo and north of Tamworth. There were reports of swaying in the upper floors of high rise buildings on the Gold Coast and in Melbourne. A felt report survey has been initiated by the

University of Queensland in conjunction with the Newcastle Police District and the ASC/BMR.

More than 4000 questionnaires have been returned. The analysis of these data has been supplemented by newspaper reports, audio reports from the ABC (Newcastle) and TV footage. Additional information is being provided by the Newcastle City Council, insurance companies, consulting engineers, other municipal councils and many hundreds of private citizens. A very detailed isoseismal map can therefore be prepared.

The levels of felt information range from the devastation in the Newcastle area to building damage up to 250km distant (eg Sydney, Scone, Kempsey), to minor damage (cracking) to feeling the effects (eg houses shaking, windows rattling, "hearing" the event). The far flung extent of the damage and the extent of the felt effects is most surprising considered that the earthquake is considered seismologically as "moderate" with a Richter magnitude of 5.6.

Strong ground motion (acceleration) data

While no near source accelerographs existed in the area at the time of the event, three vibration records are available from coal mines in the Hunter Valley. Maximum accelerations at these places some 100km from the epicentre appear to be about 3%g. A detailed analysis of these accelerations in respect of the strong ground motion attenuation relations of Rynn (1989) and Gaull et al. (1990) is in progress.

THE AUSTRALIAN BUILDING CODE

The ramifications of this earthquake to the proposed revisions to the SAA Earthquake Code AS2121-1979 and the Australian Building Code are clearly evident. With the new seismic maps of Gaull et al. (1990), the seismological and engineering information to be gained from the 1989 Newcastle earthquake provide a much better qualitative and quantitative understanding for the implementation of earthquake codes for Australian buildings.

INSURANCE ASPECTS

There is a real need to provide essential quantitative earthquake information to the insurance industry of Australia as clearly defined by the consequences of the Newcastle earthquake. The requirements include complete earthquake data catalogues, earthquake risk parameters, revision of the earthquake codes and the link of engineering to insurance. This need relates to assessing probable maximum loss using an integrated seismological-geological approach.

DISASTER MANAGEMENT

The ultimate end to all such earthquake studies is the usefulness of the information to disaster management. Australia's National Disaster Organisation, State Emergency Services and other related public services will now greatly benefit from formulating earthquake disaster plans for the future. This can only be to the benefit of all Australian citizens.

ACKNOWLEDGEMENTS

In this current research the efforts of many thousands of people must be acknowledged. While not being able to name all individually, several need special mention: Alderman John McNaughton (Lord Mayor of the City of Newcastle), Chief Superintendent Russell Cook and all his staff of the Newcastle Police District, the Police Commissioners of NSW and Queensland, members of the Queensland Government Task Force, Rotary, Apex, Lions, Professor Ian Plimer (University of Newcastle), Mr Kevin McCue (ASC/BMR) and Mrs Cynthia Hunter.

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URBAN GEOLOGY

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Urban geology can be defined as all those geological factors that influence man's ability to live in a particular area and to conduct the necessary commercial and industrial activities to sustain people and the associated infrastructure. It is not a new term for engineering geology or foundation engineering. The engineering geological characteristics of a location form but part of the body of knowledge of urban geology.

Urban geology must study the geological impact of natural hazards such as the stability of areas under earthquake shock, or the stability of an area under flood. In coastal areas the stability of the coastline under cyclonic winds or the effects of Tsunami must be included in a complete urban geological study. In hilly areas potential for landslide under heavy rain or the development of landslide or rock face failure in an earthquake is all part of urban geology.

Urban geology needs to:

(1) Be detailed, so that building by building can be considered. Maps must be prepared at a scale of 1:10,000. (This scale is the internationally accepted scale of "urban geology".)

(2) Take into account the full sequence of rock from the mantle to the surface of earth. Hence deeply buried structures or potential weaknesses that could be the focus of an earthquake must be sought. This can only be done by -

(a) deep seismic profiling

(b) use of detailed gravity studies

(c) using seismic refraction and reflection survey wherever possible

(d) high level magnetic study

(e) collating all possible stratigraphic data.

(3) Study unconsolidated sediments from fluvial and beach situations. The thickness of sediments, grain size distribution, organic content, porosity, water content, water table fluctuations due to weather, tide or river conditions must be understood.

(4) Understand the areas of soil that can be affected by rain or lack thereo:

(5) Study the geotechnical characteristics of the underlying rocks and the structural features of these near or at surface rocks.

Much information already exists in almost every major urban area of Australia, yet it remains uncollated and not readily available. A disaster such as the 28 December 1989 Newcastle Earthquake should impress on people the importance of urban geology.

P-WAVE VELOCITY IN A SYDNEY BASIN COAL : DEPENDENCE ON CONFINING PRESSURE AND WATER SATURATION

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Abstract

Compressional wave velocity and waveform measurements were conducted on six samples of evacuated dry Bulli Seam coal from West Cliff Colliery to 20 MPa hydrostatic confining pressure and 0.6 MPa pore water pressure. Increases of velocity with confining pressure (P_c) and saturation time (T) appear to be well fitted by exponential and parabolic laws of the form

$$1-\exp\left[-\frac{\left(\sqrt{P_c}\right)}{B}\right] \qquad \text{and} \qquad C\sqrt{T}$$

respectively (where B and C are constants), suggesting that such measurements may be useful for predicting stress and drainage anomalies in coal.

Introduction

One of the day-to-day needs of underground coal mining operations is the ability to predict structurally disturbed zones that are prone to gas outbursts.

One method that has the potential to do this remotely is the in-seam seismic method (Mason, 1980). Much research is being directed towards inversion of in-seam seismic data (Vozoff et al. 1987). However the interpretations rely largely upon information about dynamic properties under atmospheric and uniaxial pressure conditions (Greenhalgh & Emerson, 1986; Shea & Hanson, 1988). There is an acute shortage of information about relationships between velocity, stress and saturation in coal under conditions more relevant to actual mining operations.

This address presents some initial laboratory results as part of a long term project designed to relate physical properties of coal to stress and saturation. The ultimate aim is to provide the necessary source data for interpreting measurements from methods like in-seam seismic.

We decided to concentrate measurements initially on two simple variables: hydrostatic confining pressure and water saturation. Previous studies of sedimentary and crystalline rocks (e.g. Lama & Vutukuri, 1978) have shown that velocity, in general, increases both with increasing confining pressure and increasing water saturation. Therefore we expected to observe similar effects in coal. Here we report results for compressional (P) wave measurements.

A pressure cell was constructed to carry out the tests on 61 mm diameter core specimens to more than 20 MPa. This pressure corresponds roughly to a depth below surface of 800m. A provision for triaxial stress was included in the design to allow for subsequent, more advanced, tests. The cell is an adaptation of the Hoek cell principle incorporating matched ultrasonic transducers and pore fluid inlet lines within the axial pressure anvils (Figure 1). Porous steel discs between the anvils and the specimen assist diffusion of water into the sample. Lateral pressure is applied to the sample hydraulically through an enclosing rubber membrane.

Two 1.0 MHz Panametrics compressional wave transducers, one in each anvil, act as source and receiver for waves transmitted axially through the specimen. A Panametrics Pulser Receiver drives and receives the signal, which is then displayed on an HP 54501A digitizing oscilloscope. Time delays are measured directly from the screen of the oscilloscope. Waveform data processing is performed on a PC computer.

We conducted the measurements on six core samples from the Bulli seam, West Cliff Colliery, Wollongong. Two of these were cut for transmission parallel to bedding and four for transmission perpendicular to bedding. Balanced axial and radial (hydrostatic) pressure up to 23 MPa was used for confining pressure tests on dry samples. Water saturation tests involved injecting water at 0.6 MPa into samples under a confining pressure of 1.0 MPa. The aim of these tests was to investigate the effects of water *per se* rather than its pressure.

Full details of the experiments are given in a related paper elsewhere (Yu et al. 1990). The present paper summarizes the main observations and provides further comments on their significance.

Confining Pressure Effects

Hydrostatic confining pressure tests were carried out on evacuated dry samples.

The observed P-wave velocities (Fig. 2a) show a clear increase of around 20-30% with increasing confining pressure from 0 to 20-23 MPa. A very pronounced change occurs in the first 0-4 MPa but tails off to nearly constant velocity by 20 MPa. The velocities parallel to bedding are some 10-20% higher than those perpendicular to bedding, confirming and extending observations of Greenhalgh & Emerson (1986) for other Sydney Basin coals at atmospheric pressure. (Our atmospheric pressure velocities are similar to their measurements for Katoomba and Lithgow coals.)

The velocity dependencies on confining pressure perpendicular to bedding show good consistency and are surprisingly well fitted by an empirical relation of the form

$$\Delta V_p = A\left[1 - \exp\left(-\frac{(\sqrt{P_c})}{B}\right)\right]$$

where ΔV_p is velocity increase over zero confining pressure velocity, A is a notional maximum velocity increase at infinite pressure, and B is a constant. Mean bedding-perpendicular data from 3 to 20 MPa fit this relation within 1% for A=677 m/s, B=2.9 $\sqrt{\text{MPa}}$ and P_c in MPa (Fig. 2b). The bedding-parallel data are much less consistent but do appear to display an overall similar trend to the one just described.

Peak amplitude and frequency of smoothed waveform spectra also increase markedly with increasing confining pressure (compare Fig. 3b with 3a).

We attribute these increases in velocity, amplitude and frequency to progressive closure of small cracks with increasing normal stress. This appears to be in general agreement with the behaviour of other rock types under similar conditions (e.g. Nur, 1987).

Water Saturation Effects

Water saturation was carried out on four of the samples in an initially evacuated dry condition and held at constant water pressure (0.6 MPa) and confining pressure (1.0 MPa) for 120 hours.

Progressive increases in velocity of up to 19% parallel to bedding and up to 10% perpendicular to bedding were observed in the first 50-80 hours (Fig. 4a), with some 80% of the change taking place in the first 4 minutes. No further change appeared to take place after 80 hours.

P-wave anisotropy (1.11-1.12 ratio) was again evident in the saturated samples, but with much less dispersion than in the compressed dry samples.

Frequency and amplitude of the transmitted waves (compare Figs. 3A and 3C) increased by similar amounts to those observed in compression from 1 to 20 MPa (see Fig. 4B and 4C), except that decrease in energy absorption perpendicular to bedding was much stronger in the compression test.

The time-dependent changes in velocity during water infiltration are of interest for two reasons. (1) They demonstrate a systematic change in velocity according to the extent of water saturation at a given time. (2) The rate at which the water absorption takes place under given conditions can provide information about the permeability of the material.

To examine how these effects occurred in our tests we replotted the data as travel time (t) against square root of saturation time (T). Four distinct regions could be recognized in $t/\sqrt{T}$ space (Fig. 5):

1. An initial region of moderate linear slope which we believe is caused by initial penetration of water into the cell.
2. A region of steep linear slope and rapid travel time decrease which we propose to call 'primary saturation'.

This shows the greatest change in t and presumably represents progressive saturation of the sample along the main, interconnected, cracks.

3. A region of gentle linear slope and very slow travel time decrease following the primary saturation stage which we call 'secondary saturation'. This may be caused by the combined effect of slow, weak processes such as fluid pressure build-up within the saturated sample and penetration of remaining, poorly connected, cracks.
4. A final flat region of apparent long term equilibrium.

Additional measurements are clearly required to understand these effects in more detail. Nevertheless, they demonstrate that two different water absorption processes are operating and exert an influence on velocity during saturation. If similar processes occur in reverse, that is, during drainage of pore fluid, we expect that it will be possible to monitor different stages of fluid drainage in mines.

Conclusions

The velocities and waveforms of P-wave which we measured in coal samples from West Cliff Colliery are shown to be very sensitive both to confining pressure in the dry state and to water saturation. Preliminary results of confining pressure tests on saturated specimens (Yu et al., 1990) so far indicate that small but detectable changes in velocity occur under these conditions as well.

In practical terms, these results have implications for in-seam and cross-hole seismic methods of assisting underground coal mining exploration. From the results so far, we predict that such surveys will detect pressure-and drainage-related velocity anomalies in areas of stress relief around mine workings. Extensive further testing, combined with computer modelling, will be required to establish these relationships more fully.

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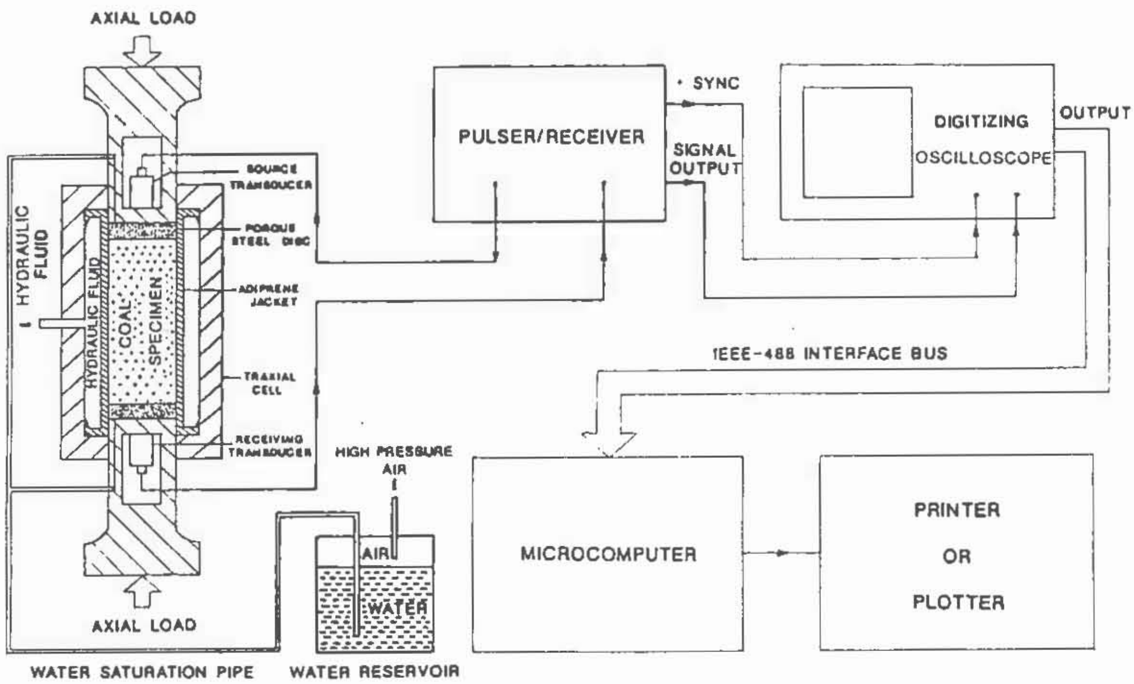

Figure 1. Schematic diagram of experimental setup.

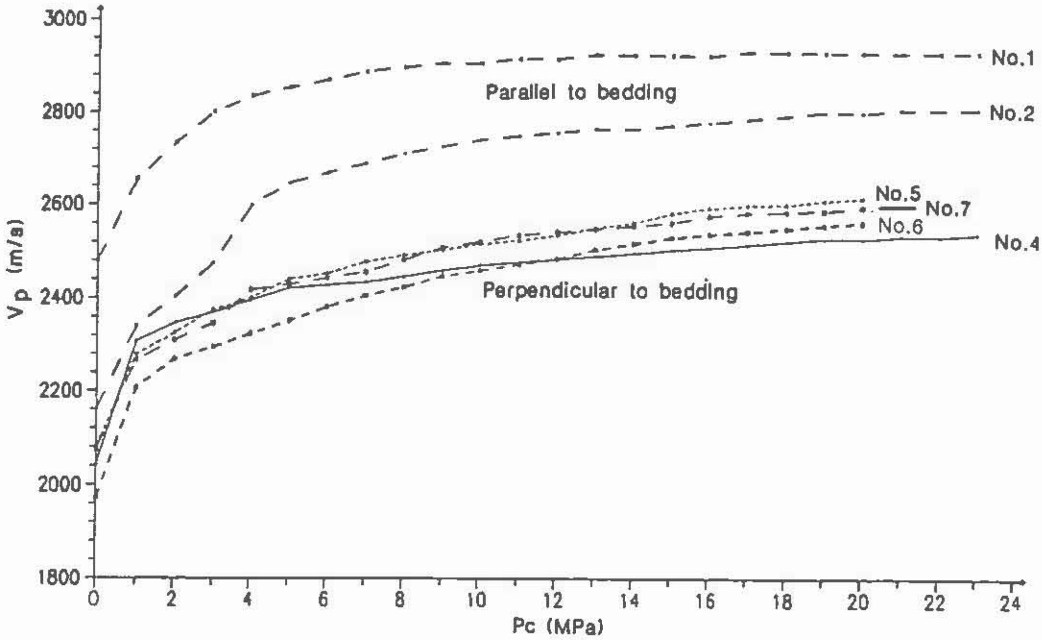

Figure 2a. Dependence of P-wave velocity (V_p) on hydrostatic confining pressure (P_c) in dry specimens. Specimens 1 and 2 cored parallel to bedding; specimens 4 to 7 cored perpendicular to bedding.

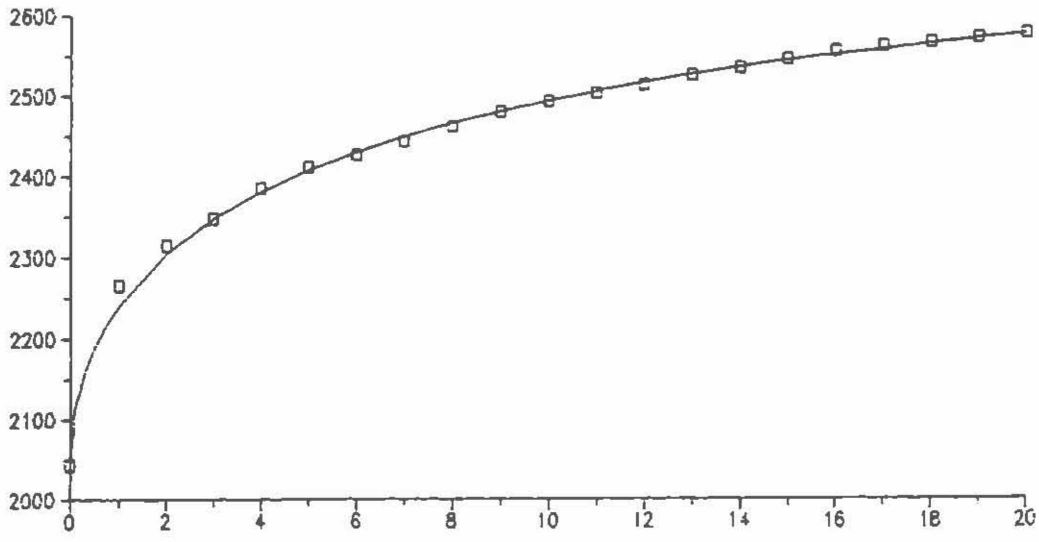

Figure 2b. Fit of mean V_p P_c data of bedding-perpendicular specimens 4 to 7 (squares) to empirical relation
V_p= 2043 + 667[1-exp(P_c 2.9)] (solid line.)

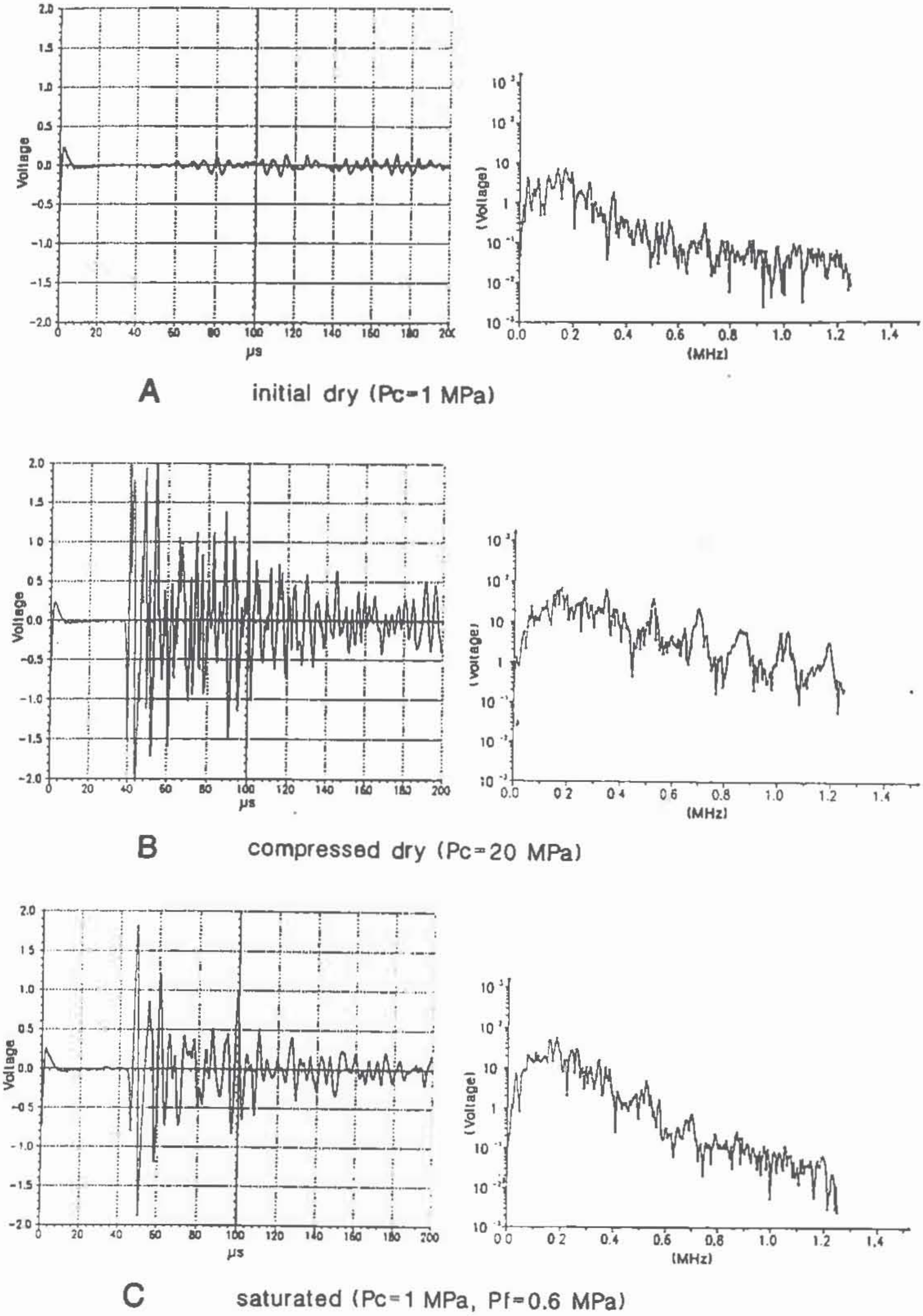

Figure 3. Waveforms (left) and FFT spectra (right) for compressional waves in specimen No.1 cored parallel to bedding. B and C show changes compared with an initial state A.

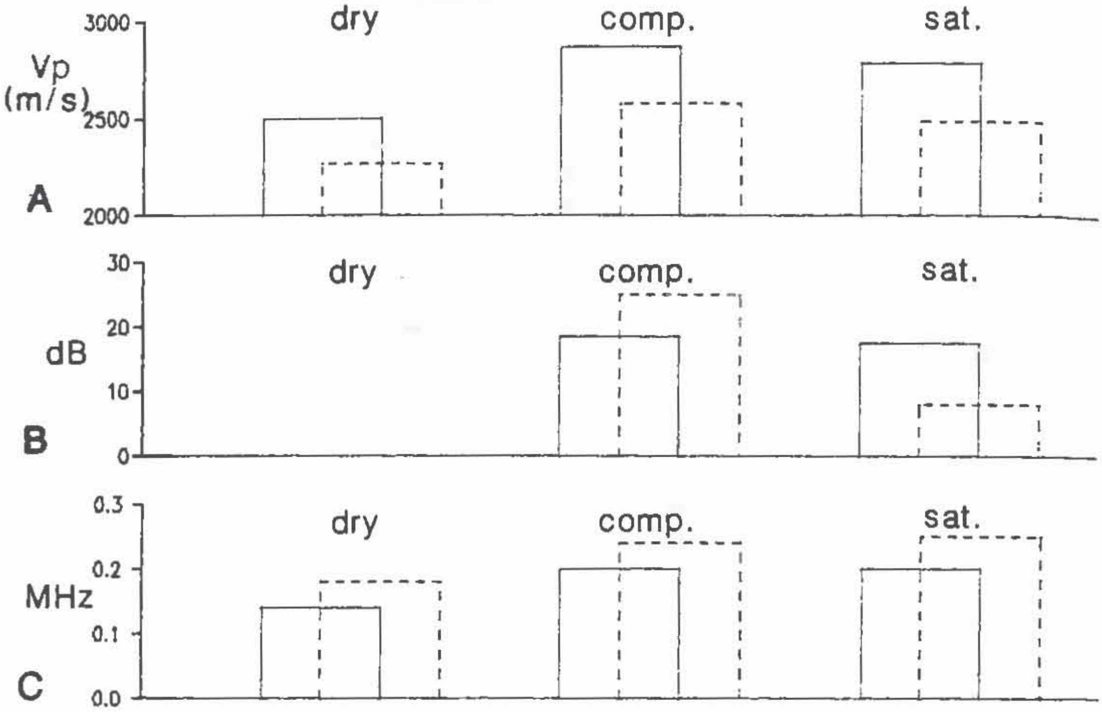

Figure 4. Bar graph summarizing mean changes in A: velocity, B: peak amplitude, C: peak frequency of P-waves from an initial 1 MPa P_c (dry) state to compressed 20 MPa P_c (comp.) and saturated 1 MPa P_c/0.6 MPa P_f (sat.) states. Solid=bedding-parallel. Dashed=bedding-perpendicular.

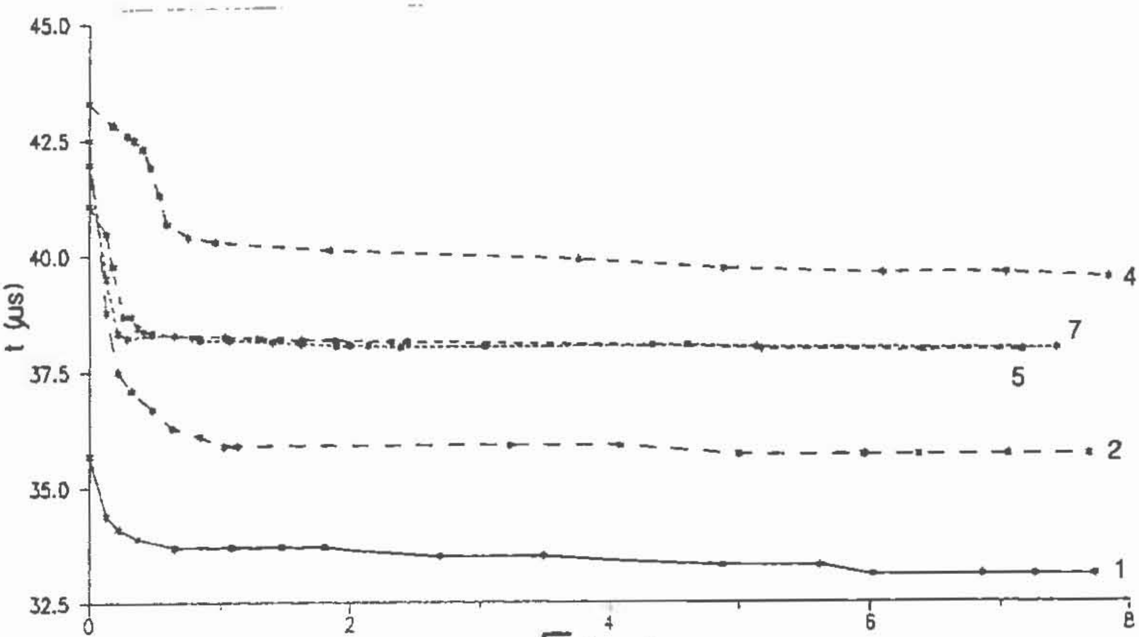

Figure 5. P-wave travel time (t) versus square root saturation time T (hours) for water saturation tests at P_c=1.0 MPa, P_f=0.6 MPa. Specimens 1 and 2 cored parallel to bedding; specimens 4, 5 and 7 perpendicular to bedding.

SPECIFICATIONS AND SOURCES OF ROCK IN THE LOWER HUNTER REGION SUITABLE FOR MARINE AND RIVER WORKS

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D.J. Douglas & Partners

1. INTRODUCTION

This paper presents: a review of the performance of some rocks currently used in the Lower Hunter Valley for rock protection on embankments and shorelines: a suggested specification for rock protection in marine and non-marine environments: and, a limited number of test results for some of the local quarries which have rock suitable for these protection works.

There has been considerable use of rock for erosion protection in the Newcastle area, particularly for river bank protection, around power stations and along the ocean front.

With the development in the region and the opening up of more quarries, there is a need for a specification for the supply of rock protection which matches the engineering requirements and materials locally available.

A number of engineering and geological aspects are important in design of rock protection works. This paper considers only one, rock durability.

2. REVIEW OF AVAILABLE SPECIFICATIONS

Various parameters have been proposed for the determination of rock protection suitability for marine and non-marine evironments. Some of these values are summarised in Table 1.

The conclusion that can be drawn from these references is that there is no universally agreed description, set of parameters, or invidividual parameter to determine suitability of rock for protection works.

VARIOUSLY RECOMMENDED ROCK TEST PARAMETERS FOR ROCK PROTECTION SELECTION

Reference	Maximum Sodium Sulphate Soundness Loss (%)	Maximum Magnesium Sulphate Soundness Loss (%)	Maximum Absorption (%)	Minimum Bulk Density (kg/m^3)	Minimum Specific Gravity	Minimum Wet Strength (MPa)	Minimum Wet/Dry Strength Ratio	Maximum Los Angeles Abrasion Value (%)
General								
Fookes & Poole, Ref 1		18	3		2.6			
Fookes & Poole, Ref 1	8 - 12		2.5		2.6	85		
PWD (NSW)					2.7			25
MSB	2.5				2.6			30
AS 1465 - 1974 Ref 2 Dense Natural Aggregate	12		5	2300				25 (Hornfels) 30 (basalt, dolerite) 45 (granite)
California Division * of Highways Ref 3	10		2		2.5			
Sedimentary Rocks in NSW								
MacGregor Ref 4 - above water table) zone - below water table) IV	30 35					12 8	25 20	
MSB	30			2300		20	75	
Electricity Commission of NSW	30*							

* Non-marine protection only

TABLE 1

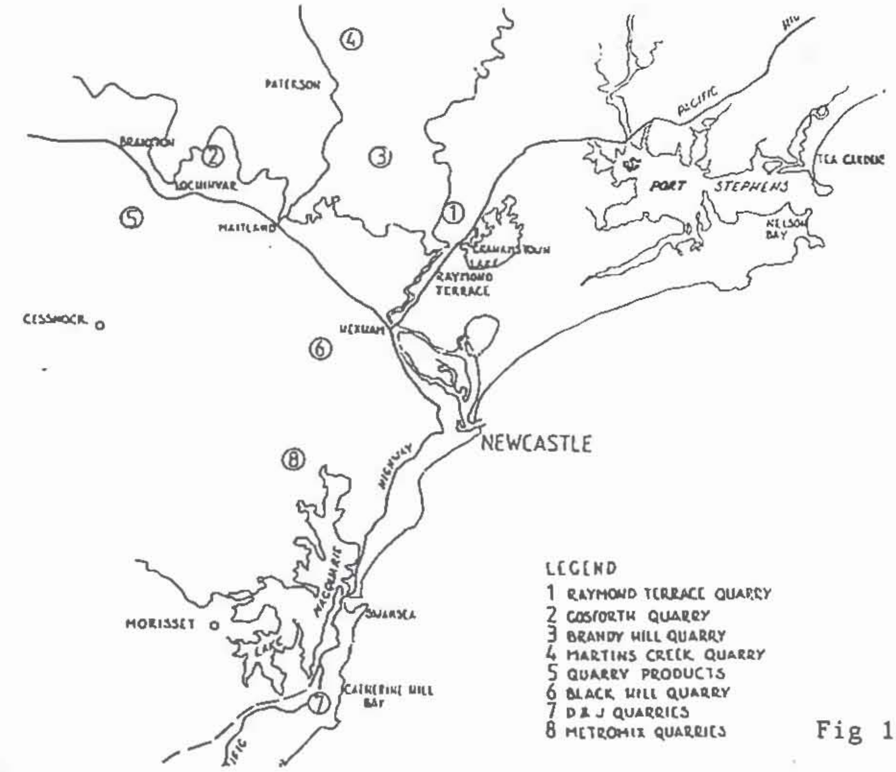

Fig 1.

ROCK PROTECTION

3. REVIEW OF LOCAL PERFORMANCE OF ROCK IN PROTECTION STRUCTURES

It is considered that where available the most important test of rock suitability is the observation of the actual performance of rock in existing protection structures. This is particularly useful if rock from the same source is to be used in future structures.

3.1 Non-marine Protection Works

The Public Works Department has constructed a number of structures around the Maitland area to control the passage of floodwaters.

These control structures are typically earth fill embankments covered by filter-sized rock, and protected by a rock blanket. This in turn is held down by 75mm mesh and anchored by steel cables.

Examination of the existing control structures near Maitland revealed that a significant proportion (15 - 20%) of the "andesite" from Martins Creek Quarry had split through apparently sound rock. A lesser proportion (5%) of the "dacite" from Raymond Terrace showed evidence of splitting.

Petrographic examination of both materials indicate that the two quarries are winning ignimbrite. Although hand specimens appeared to be unweathered, microscopically, the "andesite" was significantly more weathered than the "dacite" and had a minor amount of vermiculite developed. This suggests that petrographic analysis is essential for determining whether a source of rock is suitable or not.

Apart from mineralogical alteration playing a part in rock deterioration and cracking there also is a growing suspicion that stress relief also plays an important part.

Riverbank protection downstream from Maitland was also examined. The protection here consisted of blocks of rock up to 1m in diameter, dominantly "dacite" from the BMG Quarry at Raymond Terrace. These rocks were mostly slightly weathered but were sound with little evidence of splitting.

During the construction of the Eraring Power Station for the Electricity Commission of N.S.W. the contractors used "trachyte" from Allandale (Quarry Products) and pebbly sandstone from D. & J. Quarries, Frazer Park, as erosion protection material and free draining backfill. Detailed examination of the "trachyte" showed many incipient joint planes which weakened on exposure and caused some rock to break down. The pebbly sandstone performed satisfactorily although a sodium sulphate soundness test on -53mm sample showed 100% loss after five cycles. This sandstone also showed considerable loss of strength (approximately 75%) after five cycles of wetting and drying.

During the investigation of Bayswater Ash Dam, by the Electricity Commission of N.S.W., sodium sulphate soundness tests were carried out on samples of Muree Sandstone that had been used as rip-rap on a number of water supply dams in the area. Those samples which had performed satisfactorily gave percentage losses ranging from 7 to 43% on the 37.5mm fraction. Samples with unsatisfactory performance gave percentage losses ranging from 68 to 100%.

3.2 Marine Protection Works

The marine environment is one of the most aggressive settings which civil engineering structures have to contend with. Following Fookes and Poole (1981, Ref. 1), the marine environment may be divided into four zones:-

Zone I - Splash Zone A salt spray zone high above sea level where rock surfaces may be coated with salt due to alternative wetting and evaporation.

Zone II The zone above high water level where wave wash occurs.

Zone III - Intertidal Zone From the high tide to the lowest wave level below the low tide level.

Zone IV - Submarine Zone Permanently submerged zone below the lowest wave level.

From inspections and measurements made at local sites and from a paper by Roy (1983, Ref. 5), the following comments are made with respect to sandstone and igneous rock performance.

Sandstone from three different rock formations (see Table 2) were studied. All three sandstones show evidence of honeycomb or cavernous salt weathering in Zones I and II. Limonite cemented joint or bedding planes tend to resist weathering, eventually remaining as distinct protruberances. The estimated rates of weathering for the various sandstones are given in Table 2 for sandstones in Zones I and II.

These loss rates imply that after 50 years a one metre square block of Waratah sandstone will be of the order of 0.95 x 0.95 x 0.95m in dimensions i.e. a weight loss of about 15% while Croudace Bay Sandstone block will be of the order of 0.6 x 0.6 x 0.6m i.e. a weight loss of about 80%.

In Zone III there appears to be far less weathering and volume loss with the rock varying between subangular to subrounded in shape, implying volume losses of 5 to 15% after 50-80 years of service.

ROCK PROTECTION

Sandstone Type (Reference)	Average Rates of Regression of Exposed Rock Face
Waratah Sandstone (This study)	
. Limonite cemented	< 0.5 mm/year
. Slightly weathered to fresh	0.2-2 mm/year
Croudace Bay Formation (This study)	
. Limonite cemented sandstone and conglomerate	< 0.5 mm/year
. Slightly weathered to fresh sandstone	2.5-7.5 mm/year (average 3-5 mm/year)
Hawkesbury Sandstone (Ref 5)	
. Limonite cemented sandstone	1 mm/year
. Resistant sandstone cliff	1-2 mm/year
. "Softer" sandstone cliff	up to 5 mm/year
. Sandstone block seawalls	2-5 mm/year

TABLE 2

In regard to igneous rock, it appears that the main source of marine breakwater rock around Newcastle has been "dacite" from BMG's Raymond Terrace Quarry. This rock can be divided into two types; blue-grey, generally unaltered and green-grey, altered. The altered rock is far less durable than the unaltered rock.

These rocks, as used in breakwaters, have block sizes that generally vary from 0.5 to 1.0m in mean dimension with some blocks up to 2m in length. Many large blocks (10-30% in Port Hunter Harbour) have visible cracks or joint traces present. A small number of these cracks appear to have opened since placement, possibly due to growth of salt crystals. As with the sandstones the greatest deterioration appears to have taken place in Zones I and II with rounding of block corners, giving the following estimated volume losses:-

Estimated Volume Loss of 0.5 to 1.0m^3 Blocks		
	After 2 years	After 20-30 years
Blue-grey Dacite	1 - 2% $\pm$	5% $\pm$
Green-grey	10 - 25% $\pm$	

TABLE 3

4. SUGGESTED SPECIFICATION FOR ROCK FOR PROTECTION WORKS

Various engineering tests have been used to help assess durability characteristics of rock in an aggressive environment (Ref 6). As a result of the testing carried out on samples from potential quarries and from reference to other sources, it is suggested that the following tests are the most appropriate for determining whether a source of rock is suitable:-

- petrographic analysis,
- sodium sulphate soundness,
- specific gravity,
- saturated unconfined compressive strength,
- minimum wet/dry strength ratio,
- Los Angeles abrasion value (for marine structures).

Quarries tendering for the supply and delivery of rock for protection works should be asked to submit a run of quarry samples of rock for testing. Acceptance criteria are suggested in Table 4.

The following clauses are also suggested:-

Quality of Rock

- All rock supplied shall be hard, dense, durable and clean igneous or sedimentary (the use of sedimentary rock in marine applications infers that regular inspection and "top up" maintenance is acceptable) rock from a quarry (or quarries) approved in writing as a supply source by the Superintendent and strictly in accordance with any conditions of that approval. The rock shall be resistant to abrasion and free from cracks, cleavage planes, joints seams and other defects including unstable minerals which could result in its breakdown under either handling or placing or in a proposed environment. (Note - It may not be realistic to enforce the requirement of freedom from joints etc. if large dimension stone is required from intrusive or extrusive igneous rock).

- All rock for marine protection work shall have a Los Angeles Abrasion value of not more than 30%. (However, it should be noted that it is unlikely that sandstone will comply with this requirement. Before sandstone is rejected out of hand, it is suggested that the approximate rates of salt weathering given in Table 2 be used to determine the useful life of sandstones in a marine structure, noting that in Zones III and IV sandstone appears to be relatively unaffected by salt weathering).

- All rock shall have a minimum specific gravity of 2.6.

ROCK PROTECTION

Tests for Approval of Source Material	Acceptance Criteria
Petrographic analysis	Thin sections should be inspected by a geologist to ensure that the rock is essentially unweathered without significant quantities of deleterious minerals such as analcime and expansive clay minerals or unfavourable lineations such as micro cracks within the microfabric.
Sodium sulphate soundness (on -53 to +35mm fraction)	Igneous Percentage loss <12% Sedimentary Percentage loss <30% (<18% for non-marine applications
Specific gravity	>2.6
Saturated unconfined compressive strength	Igneous >50 MPa Sedimentary >25 MPa
Minimum wet/dry strength ratio	>50%
* Los Angelos Abrasion Value	<30%

* For marine structures - test not required for non-marine applications

TABLE 4

Quarry	Sodium Sulphate Soundness * (% loss)	Point Load Index (MPa)	Unconfined Compressive Strength (MPa) Wet	Dry	Absorption (%)	Bulk Density (kg/m^3) Dry	Saturated Surface Dry	Specific Gravity
Raymond Terrace Dacite - sound - altered	0.3 (no breakdown after 3 cycles) 63.5 (significant breakdown after 3 cycles)	9.0 1.7 8.0 11.6			0.9	2606	2678	2.67
Gosforth Quarry Rhyolite - sound	1.0 (some breakdown after 3 cycles)	10.5 5.6 6.6	36.7	62.0	4.1	2328	2422	2.57
Brandy Hill Rhyodacite - sound	0.3 (no breakdown after 3 cycles)	4.1 3.1 10.1			0.0	2623	2624	2.63
Martins Creek Andesite - sound	0.4 (no breakdown after 3 cycles)	8.1 9.3			0.9	2554	2576	2.61
Quarry Products Andesite - sound - altered	0.8 (no breakdown after 3 cycles) 33.8 (some breakdown after 3 cycles)	11.8 7.6 4.7 0.7			0.8	2648	2669	2.70
Black Hill - sandstone - siltstone - conglomerate	30.3 (some breakdown after 3 cycles) 49.6 (some breakdown after 3 cycles) 23.0 (significant breakdown after 3 cycles)	1.4 0.4	5.6		7.2	2225	2385	2.65
D. & J. Quarries - sandstone - conglomerate	23.7 (some breakdown after 3 cycles) 16.6 (some breakdown after 3 cycles)	0.8			5.1 5.4	2359 2340	2479 2467	2.68 2.68
Metromix Quarries - sandstone - conglomerate	18.0 (some breakdown after 3 cycles) 49.5 (significant breakdown after 3 cycles)	0.9 1.4	15.3	4.0	4.8	2358	2472	2.66
Boral Slag					3.2	2151	2220	2.31

* Testing on -53 to +35mm fraction

TABLE 5

- All rock in the primary armour layers shall be of such shape that the maximum dimension does not exceed two times the minimum dimension.

- All rock except that in the primary armour layer shall be of such shape that the maximum dimension does not exceed three times the minimum dimension.

Once a quarry or a particular stockpile has been approved as a source of rock by petrographic analysis and laboratory tests, the best method for identifying suitable and unsuitable material is by visual inspection, using reference samples.

Altered or fractured zones are usually obvious in the igneous rock quarries and distinctions between sandstone, siltstone and conglomerate will be necessary in the sedimentary rock quarries.

In most quarries unsuitable material is readily distinguished by alteration in colour and strength and the quarry operators generally remove this material before processing.

5. LOCAL QUARRIES

A number of operating quarries of those known around the Lower Hunter (Ref 7 & 8) have been inspected. Testing details of those quarries which produced the size and type of rock which possibly could be used for rock protection are given on Table 5. The locations of these quarries are shown on Fig 1.

All quarries inspected had some material which could be used for either control structures or bank protection. It is suggested that quarries or stockpiles be tested prior to use.

Inspection of the material available in the potential quarries around the Maitland area confirms our belief that igneous rock is suitable for marine and non-marine protection structures requiring either large or small rock (i.e. less than 300mm). Sedimentary rock may be suitable for use in non-marine protection works but, owing to its rate of volume loss, it should only be used as large blocks in marine works.

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A SEM STUDY OF THE CONCHOIDAL MARKINGS ON QUARTZ GRAINS

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INTRODUCTION

Fracture surfaces in brittle materials frequently feature two distinct structures: conchoidal marks and hackle marks. The investigation of conchoidal marks reported here is part of a research programme concerned with the damage mechanisms of rocks under tensile cyclic loading. Research on deformation mechanisms requires studies on features which can provide unambiguous information on the deformation processes. Conchoidal fracture marks are one such feature, from which valuable information on fracture propagation, history, and failure mechanisms can be obtained. The results of detailed studies of the fracture surface marks are significant not only in understanding damage mechanisms of rocks under cyclic loading, but also in providing structural geologists working on jointing with information additional to that based on joint trend geometry and orientations.

EXPERIMENTAL PROCEDURES

Chevron-notched short rod specimens cut from fluvially deposited lithic sandstones were tested with a MTS testing facility at The University of Newcastle. A detailed description of the specimen types and testing procedures can be found in Ouchterlony's paper, 1988. Rock specimens were tested under monotonic, cyclic, and sustained loading conditions. After testing, fracture surfaces were carefully prepared and subsequently examined with SEM under magnifications ranging from 1800x to 12000x.

OBSERVATIONS.

The formation of conchoidal marks is a selective process: among all the components of the sandstone specimens tested, conchoidal marks have been observed only on the fracture surfaces of detrital and authigenic quartz. The surfaces of the fractured quartz grains that show a complete conchoidal structure can be divided into 3 major zones, as shown in

Figure 1. The first zone, immediately adjacent to the origin of the crack[1], is characterized by its featureless flatness; the second zone is the conchoidal fracture mark zone, and the third is essentially flat and shows the development of hackle marks which are linear structures perpendicular to the conchoidal marks.

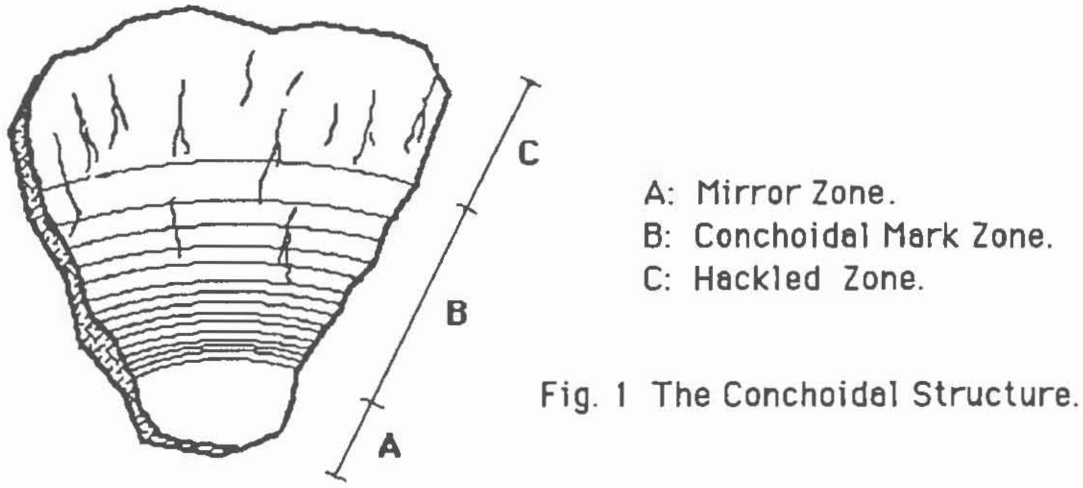

Fig. 1 The Conchoidal Structure.

The spacings between adjacent lines in the conchoidal mark zone gradually widen towards the third zone. It has been found that most conchoidal marks, especially the fine, closely spaced ones, are located in the vicinity of crack nucleation sites where the cracking speed is low. These observations are important, as they bear evidence on the velocities of fracture propagation and the intensities of fracture tip stresses.

A group of the conchoidal fracture marks formed during one crack event is characterized by a common vector in the convex direction of these marks (Fig. 2 a) or by vectors which gradually change directions (Fig. 2 b). Different groups of conchoidal marks with distinctly different convex directions, representing different crack events, can sometimes be observed on one grain.

Difficulties can occur in distinguishing conchoidal marks from the Wallner lines (Phillips *et al.* 1976) as both marks appear to be similar in several respects. However, detailed observations have shown that conchoidal marks never intersect, whereas Wallner lines do. This distinction is important, as the two types of fracture surface structures will indicate different fracture propagation velocities and processes.

In plan view, conchoidal marks are generally arranged in a

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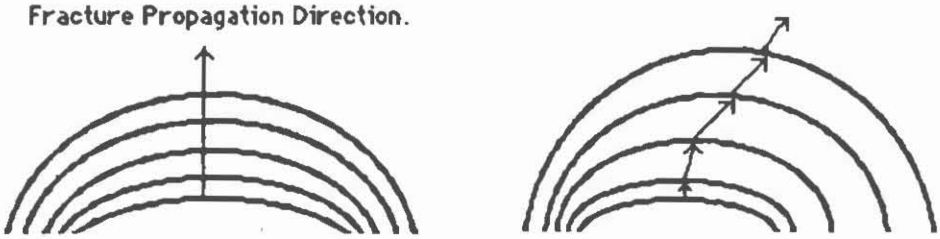
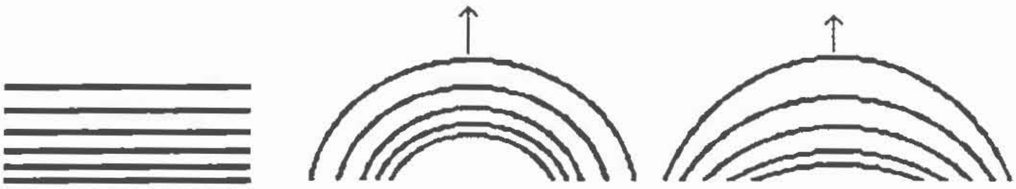
[1] The terms "crack" and "fracture" are used here interchangeably without any further specification.

concentric pattern around the point of crack origin. These patterns can be classified according to their symmetrical and geometrical characteristics, as shown in Figures 2 and 3.



a) Symmetrical. b) Asymmetrical.

Fig. 2 Conchoidal Marks of Different Symmetrical Patterns.



a) Straight Lines. b) Circular Curves. c) Elliptic Curves.

Fig. 3 Conchoidal Marks of Different Geometrical Patterns.

The conchoidal mark commonly denotes the high point of an upward-rest-downward fracture movement. A further classification based on cross-section observations shows that there are 3 main types of conchoidal fracture marks (Fig.4). The differences in geometrical parameters such as wave length (or spacing in the case of Type 3), together with variations in the symmetrical characteristics, give a large number of variants of this structure.

Fig. 4 Different types of the cross sections of conchoidal marks. The different outline patterns of fracture surfaces are produced by different patterns of the fracture tip stress variations.

DISCUSSIONS

1. Information on fracture studies provided by conchoidal marks.

Conchoidal marks are characteristic of tensile fractures; they also record the following information:

1) A conchoidal mark delineates an actual fracture front line and represents a rest-point in the forward movement of a fracture. Therefore, the geometry of this structure reflects the positions of successive past fracture fronts. The fracture tip configuration and the development history of the fracture at the time it is formed become clearly visible.

2) The fracture propagation direction is recorded by the convex direction of the structure (Fig. 2). The co-existence of several groups with the distinctly different convex directions observed is indicative of an extremely complicated crack process. In addition, the path of fracture process can be reconstructed by connecting points where the fracture velocity is greatest, as shown in Fig. 2 (Fracture velocity is to be discussed).

3) Recognition of the fracture origin is facilitated by the presence of the conchoidal structures. Statistical studies on the correlations between the sites of fracture nucleation and the rock fabric aspects will, therefore, determine the loci where fracturing is likely to occur.

4) The conchoidal marks have been commonly found to be adjacent to fracture origins where the spreading speed is low; therefore, such marks are associated with slow fracture velocities. This view is supported by laboratory tests on conchoidal mark formation in glass, during which the crack growth speed can be monitored (Murgatroyd, 1942).

5) The wave length or spacing between two adjacent mark lines at any particular point is probably the most important geometrical parameter as it is directly proportional to the fracture velocity, and thus to the intensity of fracture tip stresses at that point. Therefore, different types of the structure, as shown in Figure 2 and 3, will indicate different patterns of fracture velocity and tip stress distributions. The widening of the spaces between adjacent mark lines indicates that the fracture speed and the fracture tip stresses gradually increases from the origin of the fracture (Fig. 1). With increasing speed, the conchoidal mark zone is replaced by the hackled zone (Fig. 1), or, sometimes, by a faintly undulated surface (conchoidal marks with very large wave lengths and small wave

height), considered to be fractured at a high speed and under high stress intensity.

6) The symmetrical patterns of the structure (in plan view) correspond to the symmetry of the stresses acting on the fracturing components.

2. Study of conchoidal marks in relation to mechanisms of fatigue damage in rocks.

Studies of the fracture topography of metallic materials have enabled metallurgists to identify a few diagnostic features produced by fatigue damage and, subsequently, to establish the fatigue damage mechanisms for these materials (Lemay, 1978). The initial aim of studying the surface marks of fractured rock specimens was to ascertain whether any unique features produced by cyclic loading could be identified. Extensive studies have shown that no diagnostic feature exists in any cyclically fractured rock specimens. Although some varieties of conchoidal marks appear to resemble the fatigue striations commonly found in certain fatigued metals, all the identified varieties of conchoidal marks have been found in specimens subjected to cyclic and non-cyclic loading. The identical appearance of conchoidal marks produced under cyclic and non-cyclic conditions lies in their formation processes, which are probably due to the interactions of the material and the advancing fracture front rather than to the applied load variations

This result is an important finding, and shows that there are significant differences between damage processes in rocks and metallic materials under cyclic loading. Research results indicate that identification of fatigue damage in rocks is possible, but such identification should be based on different criteria (Li & Moelle, 1990).

One of the methods used to detect differences between damage patterns produced cyclically and non-cyclically is the statistical study of the symmetrical and geometrical characteristics of the conchoidal marks. They were mapped by a point count method and 800 crack propagation directions were recorded. The difference between crack propagation direction distribution patterns produced under cyclic and non-cyclic conditions has been found to be significant; the cyclically loaded specimens show a more complex crack pattern than that found in non-cyclically loaded specimens (Li & Moelle).

Recent statistical studies on the symmetrical patterns of the conchoidal marks show that the cyclically loaded specimens contain a larger proportion of asymmetrical patterns.

These results indicate a more complicated damage process under cyclic loading. This is consistent with statistical studies of microcrack populations in the tested specimens. A physical model depicting the fatigue damage in the tested rocks shows that the stresses in the cyclically loaded specimens are much more complex than those in the non-cyclically loaded specimens, due to the the compressive stress generated during the unloading phase (Moelle *et al*, 1989). The compressive stress induced by unloading and the resulting stress reversals with the load cyclicity, therefore, mark a fundamental difference between the physical processes, and the mechanical behaviour patterns of a given rock under cyclic and non-cyclic loading conditions.

CONCLUSIONS

Detailed studies on the conchoidal fracture marks can provide a considerable amount of information on fracture origins, paths, propagation directions, history, and conditions such as the relative fracture velocities, stress magnitudes and orientations existing at the time of the fracture event. Results obtained can be of great value to engineering geology practices, in failure prevention and analysis, and will lead to a better understanding of the joint formation.

ACKNOWLEDGEMENTS

The author thanks Dr K. H. R. Moelle for his guidance in this study and Dr J. A. Lewis for his help in the experimental programme. Mr D. Phelan assisted with the Electron Scanning Microscope, Mrs J. C. Pitts helped with the preparation of the manuscript, and Mr. E. Krupic prepared many specimens; this is gratefully acknowledged.

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DAMPED CO-OSCILLATING TIDE THEORY FOR THE GEORGES RIVER AND CALCULATION OF THE EDDY DIFFUSIVITIES

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The equations for the damped co-oscillating tide in a rectangular estuary of constant mean depth can be applied to real estuaries in which the cross section changes with distance along the estuary. The primary advantage of this method is that it eliminates the need for step wise treatment of the estuary, and results in a very large saving in time of analysis.

The difficulty of choosing a friction coefficient which is inherent in the finite difference and characteristic method is avoided by making use of information on the tidal elevations within the estuary and so have a rapid means of calculating tidal velocities in an estuary.

The two basic equations for the damped co-oscillating tide in a rectangular estuary are:

$$\sigma_{t_{HW}} = \tan^{-1}(-\tan Kx.\ \tanh \mu x) \qquad (1)$$

$$\left(\frac{\eta}{\eta_o}\right)_{HW} \sqrt{\tfrac{1}{2} (\mathrm{Cos}\ 2Kx + \mathrm{Cosh}\ 2\mu x} \qquad (2)$$

Equation (1) gives the local time of high water relative to the head of the estuary (where $\sigma_{HW} = 0$) as a function of Kx and μx.

For simplicity of notation let

$$\begin{array}{l} \quad N = \left(\frac{\eta}{\eta_o}\right)_{HW2} \\ 2 \end{array}$$

Then the above equations can be rearranged for μx and Kx as follows -

$$\mathrm{Cosh}^2\ \mu x = \tfrac{1}{2}\ (N^2 + 1 + \sqrt{(N^2 + 1)^2 - 4N^2\ \mathrm{Cos}^2\ \sigma_{t_{HW}}} \qquad (3)$$

$$\mathrm{Cosh}^2\ Kx = \tfrac{1}{2}\ (N^2 + 1 + \sqrt{(N^2 + 1)^2 - 4N^2\ \mathrm{Cos}^2\ \sigma_{t_{HW}}} \qquad (4)$$

The equations derived for the uniform rectangular estuary have been put in a form which makes possible their use in a real estuary in which the time of high water ($\sigma_{t_{HW}}$) and the elevation of high water (N) are known at various stations. Thus Kx and ηx can be determined from equations (3) and (4).

Thus Kx and μx can be determined from equations (3) and (4) for any location where $\sigma_{t_{HW}}$ are known. In the case of a real estuary, μ can no longer be considered as a true frictional damping coefficient since it includes in addition to the frictional effect, all the geometrical effects. Hence the real estuary is reduced to an equivalent rectangular estuary in which the damping term is made to account for both the frictional and geometrical characteristics.

TABLE (1)
Basic Data for Georges River Estuary

Station	Chainage x miles	in kms	Mean range in ft	Total $2n_{HW}$ in metres	Time of High Water Hours
Liverpool Weir	0	0	4.10	1.25	0
Prospect Creek	5.25	8.45	4.32	1.32	-0.08
East Hills	10.21	16.43	4.10	1.25	-0.83
Salt Pan Creek	15.23	25.51	4.06	1.24	-1.00
Lugarno	17.33	27.88	4.24	1.30	-1.67
Como	19.49	31.36	4.23	1.29	-2.00
Tom Ugly's	22.31	35.90	4.32	1.32	-2.00
Doll's Point	25.02	40.26	4.32	1.32	-2.33

The values of μx and Kx determined from equations (3) and (4) show that the relation between μx and Kx could be represented by a linear relationship of the form $\mu x = 0.75.Kx$.

With the simple relationship between μx and kx, the integration of the following equation can be carried out and the tidal velocity determined at any point.

$$V = \frac{n_{o_{HW}}.\sigma}{2Kd}\left[\text{Sin}\ \sigma_t \int_0^{Kx} (e^{-\mu x} + e^{\mu x})\ \text{Cos}\ Kx.d(Kx) \right. \tag{5}$$

$$\left. -\text{Cos}\ \sigma_t \int_0^{Kx} (e^{-\mu x} - e^{\mu x})\ \text{Sin}\ Kx\ d\ (Kx) \right]$$

I. MUMME

(1) Calculations of $\frac{n_{o_{HW}}.\sigma}{2Kd} = \frac{2.05}{2} \frac{\sigma}{K} \times \frac{1}{14}$

Now $\frac{\sigma}{K} = C = \sqrt{gd} = 21.2$ ft/second $= 6.46$ metres/second

$$\frac{n_{o_{HW}}.\sigma}{2Kd} = \frac{2.05}{2} \times 21.2 \times \frac{1}{14} = 1.55$$

(2) Calculation of

$$\int_0^{Kx} (e^{-\mu x} + e^{\mu x}) \text{ Cos } Kx \text{ d } (Kx) = \int_0^{Kx} (e^{-0.75\,Kx} + e^{0.75\,Kx}) \text{ Cos } Kx \text{ d } (Kx)$$

$$= \int_0^{Kx} e^{(-0.75Kx)} \text{ Cos } Kx \text{ d } (Kx) + \int_0^{Kx} e^{0.75Kx} \text{ Cos } Kx \text{ d } Kx$$

Now

$$\int_0^{Kx} e^{-0.75Kx)} \text{ Cos } Kx \text{ d } (Kx) = \frac{e^{-0.75\,Kx}}{(-0.75)^2 + 1^2} (-0.75 \text{ Cos } Kx + 1 \text{ Sin } Kx)$$

$$= \frac{e^{-0.75\,Kx}}{1.56} (0.75 \text{ Cos } Kx + \text{Sin } Kx)$$

Also

$$= \int_0^{Kx} e^{0.75\,Kx} \text{Cos } Kx \text{ d } (Kx) = \frac{e^{0.75\,Kx}}{(0.75)^2 + 1^2} (0.75 \text{ Cos } Kx + 1.\text{Sin } Kx) =$$

$$\frac{e^{0.75\,Kx}}{1.56} (0.75 \text{ Cos } Kx + \text{Sin } Kx)$$

$$\int_0^{Kx} (e^{-\mu x} - e^{\mu x}) \text{ Sin } Kx \text{ d } (Kx) = \int_0^{Kx} (e^{-0.75\,Kx} \pm e^{0.75\,Kx}) \text{Sin } Kx \text{ d } (Kx)$$

$$= \int_0^{Kx} e^{-0.75\,Kx} \text{Sin } Kx \text{ d } (Kx) - \int_0^{Kx} 1^{0.75\,Kx} \text{Sin } Kx \text{ d } (Kx)$$

$$\int_0^{Kx} (e^{+0.75\,K^x} \operatorname{Sin} Kx \, d\,(Kx) = \frac{e^{0.75\,Kx}}{(0.75)^2 + 1^2} (+0.75 \operatorname{Sin} Kx)$$

$$- 1 \operatorname{Cos} Kx \, d\,(Kx) = \frac{e^{0.75\,Kx}}{1.56} (0.75 \operatorname{Sin} Kx - \operatorname{Cos} Kx)$$

Therefore:

$$= \int_0^{Kx} (e^{-\mu x} + e^{\mu x}) \operatorname{Cos} Kx \, d\,(Kx) = \frac{e^{-0.75Kx}}{1.56} (-0.75 \operatorname{Cos} Kx$$

$$+ \operatorname{Sin} Kx) + \frac{e^{0.75\,Kx}}{1.56} (0.75 \operatorname{Cos} Kx + \operatorname{Sin} Kx)$$

and

$$= \int_0^{Kx} (e^{-\mu x} + e^{\mu x}) \operatorname{Sin} Kx.\ d(Kx) = \frac{e^{-0.75\,Kx}}{1.56} (-0.75 \operatorname{Sin} Kx - \operatorname{Cos} Kx)$$

$$, \quad \frac{e^{0.75\,Kx}}{1.56} (0.75 \operatorname{Sin} Kx - \operatorname{Cos} Kx)$$

Thus:

$$\operatorname{Sin} \sigma_t \int_0^{Kx} (e^{-\mu x} + e^{\mu x}) \operatorname{Cos} Kx \, d\,(Kx) = \operatorname{Sin} \sigma_t \quad \frac{e^{-0.75\,Kx}}{1.56}$$

$$(-0.75 \operatorname{Cos} Kx + \sin Kx) + \frac{e^{0.75\,Kx}}{1.56} \quad (0.75 \operatorname{Cos} Kx + \operatorname{Sin} Kx)$$

Also

$$\operatorname{Cos} \sigma_t \int_0^{Kx} (e^{-\mu x} - e^{\mu x}) \quad \operatorname{Sin} d\,(Kx)$$

$$= \operatorname{Cos} \sigma_t \ \frac{e^{-0.75\,Kx}}{1.56} (-0.75 \operatorname{Sin} Kx - \operatorname{Cos} Kx)$$

$$- \frac{e^{0.75\,Kx}}{1.56} (0.75 \operatorname{Sin} Kx - \operatorname{Cos} Kx)$$

Thus we can compute the tidal velocity at any point in the George's River estuary from equation (5). By using the data presented in Table (1) the velocities were computed for the various cross sections listed and are presented in Table (2).

TABLE 2

Tidal Velocities for George's River Estuary

Station	Tidal Velocity in (feet/sec)	(metres/second)
Liverpool Weir	0	0
Prospect Creek	0.013	0.00396
East Hills	0.81	0.0247
Salt Pan Creek	1.44	0.439
Lugarno	1.30	0.396
Como	2.05	0.625
Tom Ugly's	2.18	0.664
Doll's Point	2.44	0.744

Using an empirical equation derived by Harleman (1961 for calculating the eddy diffusivities in a real estuary, namely:

$$E_A = 77 \cdot \frac{(0.023)}{RH^{\frac{1}{6}}} \cdot \frac{2}{\pi} \cdot V_T \cdot Rh$$ where E_A = the eddy

diffusivity at a cross section A, V_T = the average maximum tidal velocity at a cross sectional area A, Rh = the hydraulic radius at the cross sectional area A, the eddy diffusivities were calculated at the various cross sections investigated, and the results are brought together in Table (3).

TABLE (3)

Computed Eddy Diffusivities for Selected Cross Sections of the George's River Estuary

Cross Section	Rh (ft)	Rh (m)	V_T (ft/sec)	V_T (m/sec)	$\frac{1}{RH6}$ f units	$\frac{1}{RH6}$ m units	E_A (ft^2/sec)	E_A m^2/sec)
Liverpool Weir	7.591	2.314	0	0	1.481	0.870	0	0
Prospect Creek	4.500	1.372	0.132	0.040	1.285	0.949	0.518	5.63
East Hills	8.86	2.70	0.81	0.247	1.44	0.847	6.98	74.89
Salt Pan Creek	19.154	5.84	1.44	0.439	1.115	0.745	19.3	209.78
Lugarno	10.33	3.15	1.30	0.40	1.49	0.826	10.2	110.9
Como	14.48	4.41	2.05	0.625	1.56	0.781	21.5	233.7
Tom Ugly's	24.50	7.47	2.18	0.66	1.70	0.715	35.6	386.96
Doll's Point	6.93	2.11	2.44	0.74	1.38	0.883	13.56	147.39

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MEASUREMENTS OF SOIL EROSION IN THE SYDNEY - HUNTER VALLEY REGION

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INTRODUCTION

Recent articles in Search have suggested that the soil is essentially a non-renewable resource (Beckmann and Coventry 1987; Edwards 1988). This paper examines measured rates of soil erosion under conditions of intensive rural use and urban development in relation to soil losses occurring within natural forest in the Sydney - Hunter valley region.

Three scale-related methods of soil-loss measurement have been employed:

(i) plots, $2m^2$ - $100\ m^2$ in area
(ii) caesium-137 tracer techniques (>0.25 ha), and
(iii) catchment sediment yield (> $1\ km^2$)

EROSION PLOT STUDIES

Plots used for measuring soil loss have fixed boundaries, and runoff and sediment are caught in a trough and led through a pipe to a collection tank. Because of their small size, plots are used to measure sheet and shallow rill erosion. Rates of soil loss are expressed in mass per unit plot area, per unit time (equivalent to t/ha/y).

Soil loss under eucalypt woodland and forest

Thirty-seven plot-years of soil loss data are available for open eucalypt forest (canopy cover 30-70%) within Maluna Creek catchment at Pokolbin. Soil losses ranged from 0.02 to 0.44 t/ha/y. Within the Royal National Park, Atkinson (1984) estimated soil loss under natural groundcovers as between 0.17 and 1.40 t/ha/y.

A study of soil erosion following a moderately intense bushfire in dry sclerophyll forest near Narrabeen Lagoon was conducted in 1980 (Blong et al. 1982). Sediment yields from three plots were between 2.5 and 8 t/ha/y. Because of low rainfall, these losses may be underestimates, and rates of 20 t/ha/y could be more reasonably expected (Blong et al. 1982). Atkinson's (1984) study of the bushfire effects in the Royal National Park suggest soil loss rates in excess of twice this amount. Recovery to pre-fire hydrologic conditions will depend on the rate of vegetation regrowth, which was, for example, four to five years in the Snowy Mountains (Brown 1972).

Soil loss under grazing

In the upper Hunter valley soil loss from one plot under grazing was 1.04 t/ha/y (5 years) (Elliott and Dight 1987). Edwards (1988) reported a mean plot-loss of 0.21 t/ha/y (N = 43, median = 0.05 t/ha/y, stand. deviation 0.40 t/ha/y) for long-term plots of the Soil Conservation Service of NSW which experienced moderate to heavy grazing pressures. Ungrazed grass-covered plots at Maluna experienced losses between 0.29 and 0.49 t/ha/y (22 plot-years), and at Howick 0.91 t/ha/y (one plot, 5 years: Elliott and Dight 1987).

Soil loss under rehabilitated overburden

At Foybrook and Howick open-cut coal mines in the upper Hunter, soil losses from 2 m^2 plots on rehabilitated overburden were studied over a five-year period (Elliott and Dight 1987). On topdressed overburden, soil losses for the total study period were 3.01 (grazed) and 2.41 (non grazed) t/ha/y at Howick. At Foybrook the rates were 0.43 and 0.53 t/ha/y, respectively. Bare overburden at Foybrook yielded 11.77 t/ha/y for the same period (Elliott and Dight 1987).

Soil loss from bare plots

Because of the difficulty of establishing and maintaining plots within working agricultural environments, soil losses from bare surfaces can be considered as "worst possible" cases for agricultural systems (Edwards 1988). At Maluna, losses from bare plots ranged from 12.44 to 33.96 t/ha/y (19.4 plot-years), while Rosewell (1986), reported in Edwards (1988), recorded rates averaging between 31 and 87 t/ha/y under similar conditions.

TRACER TECHNIQUES: CAESIUM-137

The transfer of knowledge gained from small plot experiments to larger-scale working environments has been a major difficulty for students of soil erosion. Recently, isotope tracer techniques have provided a methodology which can give qualitative and sometimes quantitative estimates of net soil loss (McHenry 1985).

SOIL EROSION

The isotope caesium-137 (Cs-137, half-life 30 years), an atmospheric fallout product of thermonuclear weapons testing, becomes rapidly and firmly adsorbed on to surface soils on reaching the earth. It therefore becomes an effective tracer of soil movement (Loughran et al 1988a). The availability of long-term records of soil loss from plots in eastern Australia has enabled the establishment of calibration curves of percentage Cs-137 loss (compared with the local reference input) against soil loss (Loughran et al. 1988a and 1988b).

An alternative calibration of Cs-137 loss to soil loss for cultivated soils assumes that:

(i) Cs-137 is uniformly mixed in the plough layer;
(ii) the % Cs-137 depletion is directly proportional to the depth of plough layer lost, and
(iii) fallout of Cs-137 and soil erosion have been temporally uniform. (Martz and de Jong 1987; Loughran 1989).

Calculation of net soil loss from calibration curves

Within Maluna Creek catchment at Pokolbin, Cs-137 was mapped on two vineyard blocks using 10 x 10 m grid sampling. Lines of equal Cs-137 content (isocaes) were plotted and compared with reference input. A calibration curve of percentage Cs-137 loss v. soil loss was used to draw lines of equal soil erosion (isoerosols) (Campbell et al. 1986). Estimated net soil losses were 6.8 and 5.9 t/ha/y for malbec and pinot noir vineyard blocks, respectively.

Using the same methodology on a wheat-pasture rotation at Merriwa in the upper Hunter, estimated soil losses were between 0.42 and 2.54 t/ha/y over a 6.6 ha area (Loughran et al. 1988b).

Calculation of net soil loss by the proportional method

Estimates of soil erosion by the proportional method were ten or more times greater than by the calibration curves. For the Maluna malbec and pinot noir vineyards respectively, losses were 66 and 70 t/ha/y. At Merriwa, the estimates were between 8 and 37 t/ha/y (Loughran et al., 1990).

Factors contributing to underestimation by the curves and overestimation by the proportional method are discussed in Loughran et al. (1990).

CATCHMENT SEDIMENT YIELD

Suspended-sediment sampling of stream flow in conjunction with the hydrograph can be used to determine drainage basin sediment yield (Loughran, 1977).

Four studies have been conducted within rural and urbanised catchments in the lower Hunter - Lake Macquarie area.

Rural sediment yields

(i) Congewai Creek: This catchment is situated south of Cessnock and forms the headwaters of Wollombi Brook. Sediment yields through four progressively downstream sites were measured for one year. There was an increase in yield downstream from 7.4 to 16.2 t/km²/y (Loughran 1975). The percentage cover of eucalypt forest decreased downstream, while grazing land on cleared slopes and the valley floor increased in area (Table 1).

A further year's record was collected (1973-74) at the most downstream station (Eglinford), and the yield was 43.2 t/km²/y. The second year had above average (+72%) runoff (Loughran 1977).

Using event-based extrapolation, a ten-year sediment yield estimate at Eglinford was 14.1 t/km²/y (1968-77) (Loughran 1979) (Table 1).

(ii) Deep Creek at Pokolbin: Geary (1981) measured suspended sediment for a 14 month period at two stations within Deep Creek basin, Pokolbin Nos 4 and 3 of the NSW Water Resources Department (Table 1). Site 4 (5 km²) had a sediment yield of 121 t/km²/y and Site 3 (25 km²), 232 t/km²/y. Forest cover decreased downstream, while the percentage area of vineyards and grazing land increased (Table 1).

Table 1

CONGEWAI CREEK SUSPENDED SEDIMENT YIELDS
(Loughran 1975, 1977 & 1979)

Area above site (km²)	Length of record	Sediment yield t/km²/y	Land use Forest %	Land use Grazing %
34	1970-71 (1 y)	7.4	95	5
71	1970-71 (1 y)	7.6	87	13
78	1970-71 (1 y)	8.8	84	16
86	1970-71 (1 y)	16.2	83	17
86	1973-74 (1 y)	43.2	83	17
86	1968-77 (10 y)	14.1	83	17

Cont...

DEEP CREEK SUSPENDED SEDIMENT YIELDS
(Geary 1981) 1976-77 (1.2 years)

Area above site (km^2)	**Sediment yield $t/km^2/y$**	**Land Use %**		
		Vines	**Forest**	**Grazing**
5	121	4	50	46
25	232	13	20	67

(iii) Maluna Creek at Pokolbin: Maluna catchment forms a sub-basin (1.7 km^2) above Pokolbin No 4. Sediment yield for three years (1978-81) was 50 $t/km^2/y$, a period of below average rainfall and runoff. It was estimated that more than 90% of the sediment output was derived from vineyards which made up only 10% of the basin area (Loughran et al. 1986). An estimate of longer term sediment yield (1971-87 : 16.5 years) gave an average of 208 $t/km^2/y$.

Sediment yield from a partially urbanised basin

At Carey Bay, near Toronto, a six-month study of sediment transport through three stations was conducted by Roberts (1986). The catchment was subdivided into three parts: forest, forest and older urban, and recent urban. Yields were the equivalent of 9.6, 14.1 and 26.1 $t/km^2/y$ respectively. Taken separately, the older urban was estimated to have yielded 29.2 $t/km^2/y$.

DISCUSSION

Plot studies of soil erosion have the disadvantage of sampling only a small portion of a natural slope system because plot boundaries prevent the runon of water and sediment from upslope. Therefore, plots can be used only for comparative purposes, and measured soil losses may be regarded only as estimates. Nevertheless there appears to be reasonable agreement between the studies reported in this review, despite variations in the length of study periods and incident rainfall.

Under forest, plots tend to have soil losses below 0.5 t/ha/y. Only Atkinson (1984) reports an estimated loss above this figure. After forest fire, evidence suggests soil loss rates will increase eight to twenty times, although expected rates of decline due to revegetation could not be estimated (Blong et al. 1982). Rates of soil loss from grazed or ungrazed grass-covered plots were only marginally greater than under forest. At the very most, losses were one t/ha/y. Top dressed overburden, on average, yielded soil losses which were not significantly different from those on native pasture. Where ground cover was absent from plots in three studies, soil loss rates between 20 and 180 times greater than under forest were experienced. This conclusion is confirmed by the Cs-137 technique.

Estimates of soil erosion from catchment studies of sediment yield are difficult to interpret for a number of reasons. Point sources of sediment within a basin vary both in space and time, and much of the eroded sediment may not be delivered to the stream system. Few studies of sediment transport measure bed load. Thus the linkage between on-site slope erosion and sediment yield from a catchment is difficult to determine. Nevertheless, the catchment studies reported here strongly suggest that increased disturbance due to forest clearance, grazing, cultivation and urbanisation can increase sediment yields between two and twenty times.

CONCLUSION

Measurements of accelerated soil erosion must be compared with "background" levels of soil loss because rates of soil formation are unknown (Beckmann and Coventry 1987; Edwards 1988). The temporal and spatial variability of erosion will always create problems for interpretation, but the Cs-137 technique is now being widely used to provide information on soil erosion status, time-averaged since the mid-1950s.

Despite the above difficulties, recent studies have shown that most severe accelerated erosion occurs when all groundcover is lost, either by fire or cultivation. Loss of soil nutrients and water pollution will result under such circumstances. Where groundcover is maintained after forest clearance, the soil losses appear to be close to "background" on native pasture and rehabilitated overburden.

ACKNOWLEDGEMENTS

The help of Mr Allan Williams in setting up and running field projects at Congewai and Pokolbin is gratefully acknowledged. Mr Darren Shelly, Research Assistant, National Soil Conservation Program, provided invaluable support, and Mr Neil Gardner helped with field measurements at Maluna. Funding was provided by NSCP, ARC (ARGS/ARGC), ANSTO, the Soil Conservation Service of NSW and the University of Newcastle.

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STRUCTURAL TRENDS IN THE UPPER NARRABEEN GROUP

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INTRODUCTION

Over the last decade more has been written about the structural and geotechnical properties of the Hawkesbury Sandstone (McMahon and McMahon 1980, Pells 1985) and Ashfield Shale (Branagan 1988) than about the Narrabeen Group. What has been written on the Narrabeen Group has mainly concentrated on its depositional history and lithology (Guide to Sydney Basin, Bembrick et al (1980)) and geotechnical properties (Pells, 1985).

It is the objective of this paper to briefly discuss the types of faulting and joint patterns common in the Upper Narrabeen Group as observed on headlands of Sydney's northern beaches.

FAULTING

(a) Upper Sandstone Unit

Detailed mapping of headland geology (Fig. 1) and structure reveal two distinct types of faulting that are possibly related to both geology and variations in stress.

Cliffline geology between Dee Why and North Head is dominated by fine to medium grained, quartz lithic sandstone of the Newport Formation. Along this part of the coast, joint swarms similar to those identified in the Hawkesbury Sandstone by Branagan (1988) are common.

At "Old Man's Hat" inside North Head, joint swarms are about 800 m apart and strike 030° with a zone of influence about 100 m wide. One swarm can be traced right across the headland for almost 2 km. Joints within this swarm extend the full 20 m height of the cliff line, are straight and show no signs of horizontal displacement. Joint spacing near the centre of the zone is less than 2 m with the joints near vertical. Progressing away from the centre, joint spacing increases while the dip decreases until near the outer eastern limit of the swarm, joints are almost 8 m apart and dip 75°W. On the western limit, the joints dip east.

At Dee Why Head another joint swarm was observed striking 027°. Joint spacing in the central sheared zone varied between 1 - 2 m with the joints near vertical and extending the full height (50 m) of the headland. The zone of influence is asymetric extending 40 m to the south-east and 100 m to the north-west where joint spacing increases to 20 m with dips of about 60°SE. No horizontal or vertical displacements could be detected.

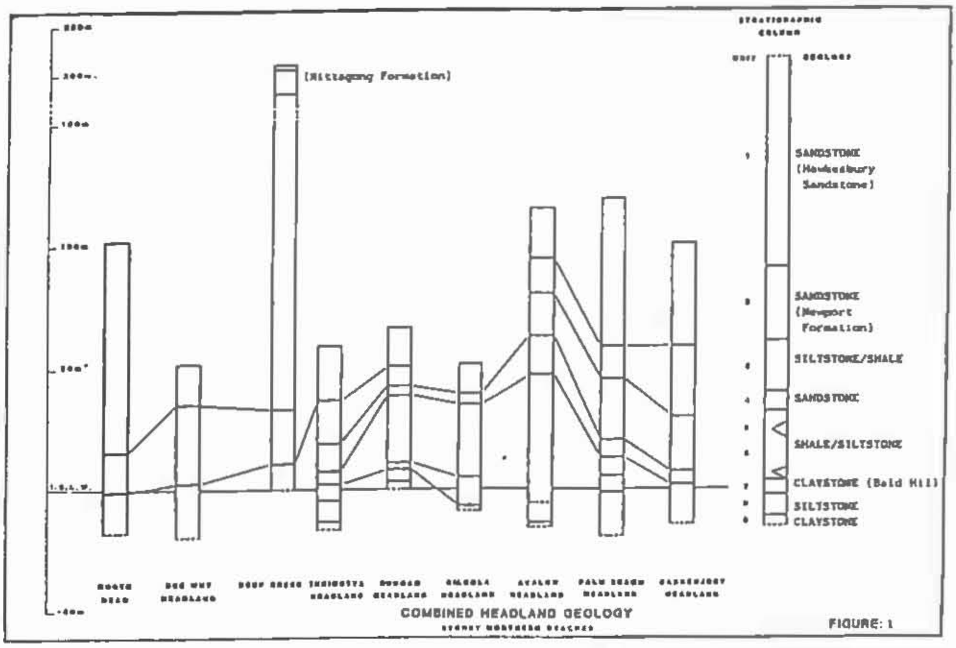


FIGURE: 1

(b) <u>Shaley/Claystone Units</u>

As a consequence of low amplitude folding along the coast, a structural high between Long Reef and Bilgola results in the exposure of the Bald Hill claystone on many of the rock platforms.

Mapping of Narrabeen, Turimetta and Mona Vale Headlands reveals variation in faulting style within the different rock types. At both Narrabeen and Turimetta Heads where interbeds of shale and siltstone dominate, normal faulting was observed either as single fault planes or as zones comprising a number of fault planes.

Fault strikes varied between 135° and 156° with dips of 60° - 65° NE and 45° SW. Generally, fault planes were straight with displacements of less than 1 m. The frequency of faulting appeared to increase northwards and was often concentrated around platform level, with the suggestion that some faults extend through the headland.

At Turimetta Head the Bald Hill Claystone was exposed at platform level; normal faulting was common with displacements of less than 300 mm. Most faults were strongly slickensided and wavy with similar wavy discontinuous joints (<0.05 m long) common at the northern end of the headland. Faults could often be traced for a distance of over 20 m along the platform.

At Mona Vale headland, a large concave fault was observed. The geology of this headland is similar to Turimetta headland but faulting above the Bald Hill Claystone was less intense. Midway along the headland a 20 m high concave normal fault striking 049° displaces the Bald Hill claystone by about 1.5 m. This fault can be detected some 140 m away on the northern side of the headland. Faulting over the rest of the headland was sparse with only a few normal faults striking 56° and 037°.

In general faulting on outer rock platforms and cliffs was more prevalent on headlands dominated by shales.

JOINTING

From detailed mapping of cliffline and rock platforms, joint orientations show agreement with joint and major structural trends observed elsewhere within the Sydney Basin (Bembrick et al 1973).

Structural trends of individual headlands showed a slight shift in pole concentrations, possibly the result of minor folding along and across the coast (Packham 1984). Details of joint pole concentrations and eigen values for individual headlands are summarized in Table 1.

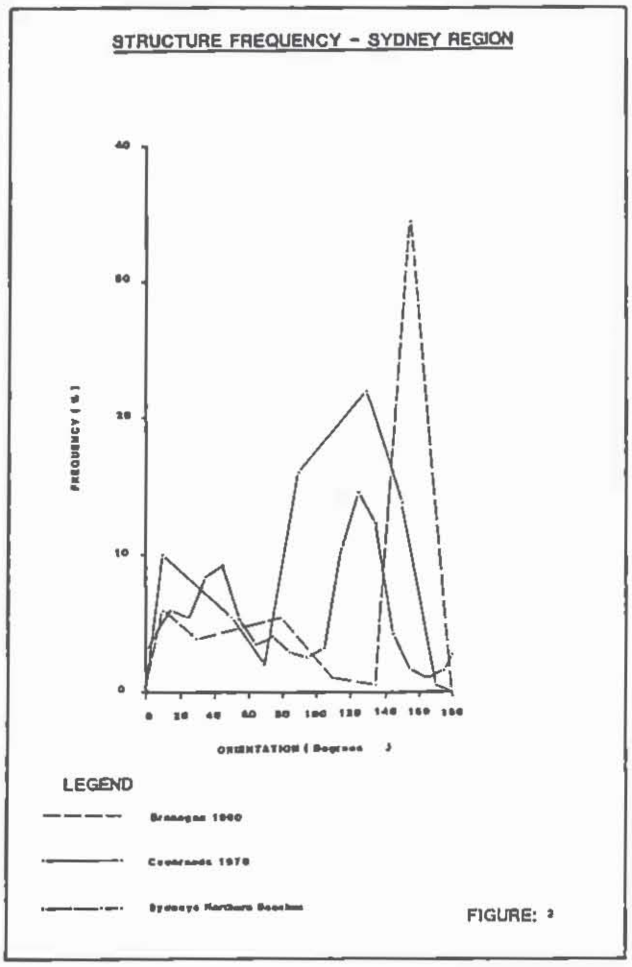
TABLE 1

Headland	Pole Concentrations (Az)		Eigen Values (Az)		No.of Poles
	Major Dip Az	Secondary Dip Az	Major Dip Az	Secondary Dip Az	
North Head	08°/115°	10°/202°	03°/114°	06°/205°	69
Dee Why Head	06°/218°	02°/287°	06°/238°	02°/148°	146
Narrabeen Head	06°/306°	16°/200°	08°/308°	11°/171°	254
Bilgola Head	07°/132°	10°/070°	04°/125°	09°/080°	148
Avalon Head	03°/315°	10°/212°	03°/303°	05°/176°	284
Palm Beach	04°/304°	15°/025°	03°/265°	03°/067°	124
Barrenjoey	04°/302°	10°/212°	01°/351°	02°/261°	78

Note: Eigen Values are statistically calculated joint pole concentration

Major pole concentrations around 305°Az were observed on Narrabeen, Palm Beach and Barrenjoey Headlands. However the anti-clockwise rotation (from 315°Az to 302°Az) of joint azimuths north of Bilgola, up the stratigraphic column should be noted. Marked changes in structural domains between other headlands could be the result of major faulting.

It was not possible to identify any positive trend in regional joint pole concentrations down the stratigraphic column as observed by Shepherd et al (1981) in other parts of the Sydney Basin, but a comparison of joint frequency distribution with that of Coneraads (1978) shows close agreement (Fig. 2).



CONCLUSIONS

Although structural trends within the upper Narrabeen Group vary between headlands, it is difficult to identify a relationship between joint and fault trends. It is possible though to identify different styles of faulting that relate to geology. Joint swarms similar to those identified in the Hawkesbury Sandstone are common in the Newport Formation Sandstone. Planar to concave normal faulting is dominant in the lower shaley units adjacent to the Bald Hill Claystone.

UPPER NARRABEEN GROUP

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IMAGE ANALYSIS OF CHAR FROM PYROLYSED LITHOTYPE CONCENTRATES

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The objective of the project reported here is to determine the effect of petrographic content of isometamorphic feed coals on the burnout level and the char morphologies they produce in a drop-tube furnace. Concentrates of various coal lithotypes with similar ash contents, and often very similar volatile matter content were collected and characterised by maceral, microlithotype and FTIR analyses.

The full char classification system outlined previously (Bailey et al, 1990) was used to characterise the pyrolysis residues of the concentrates according to their porosity, pore size distribution, wall thickness and anisotropy. Computerised image analysis of the high temperature pyrolysis residue of the concentrates was carried out, and the relationship of parameters such as sphericity, porosity, char type and particle size to the burnout level, and petrography of the coal feed, was assessed. The Leitz Bioquant system was used for the char analysis. Significant differences were established between the char types produced from different lithotype fractions.

Rank (mean random vitrinite reflectance) of the feed coal is still found to be the best predictor of unburnt carbon levels in combustion residue at 1000°C and at industrial scale if the coals concerned have ranks which differ by >0.1% R_{ort}. However, rank is not an adequate predictor of burnout performance of isometamorphic coals (differ by <0.09%) R_{ort}).

Broad char groups defined according to the char classification system are found to be related to groupings of microlithotypes in the feed coal defined according to a modified microlithotype definition for pulverised fuel (Bailey et al, 1990). Testing of lithotype concentrates both by burnout experiments and by morphometric analysis of their char, allows a study of the combustion behaviour of the individual components of coal, with the possibility of applying systematic separation of lithotypes to the industrial process. Current open-cut mining methods allow separate stockpiling of broad lithotype groups, and a knowledge of the petrographic makeup of an energy seam and the relative combustion performance of its components would allow optimum blending, and optimum process conditions for the coal being fed to the furnace at any time.

Chars Analysed

Chars produced at 1500°C are the most completely devolatilised pyrolysis chars able to be produced in the current experiments, and most closely resemble unburnt carbon in flyash, and so have been chosen to be studied by quantitative image analysis in order to most closely estimate burnout performance.

A significant correlation exists between high density char fractions formed by both pyrolysis and combustion. The correlation between the amount of high density and thick-walled pyrolysis char and total unburnt carbon has a correlation coefficient of 0.83, and that between high density and thick-walled pyrolysis char and high density combustion residue is 0.87. High density and thick-walled pyrolysis char here includes crassispheres, mesospheres, mixed dense, inertoids, solid and fusinoid char.

For this reason and because pyrolysis chars, even those produced at 1500°C, are much less fragmentary and more identifiable morphologically than combustion char produced at 1000°C, high temperature pyrolysis char has been chosen for quantitative image analysis.

Separation of Lithotype Concentrates

Other workers (Dyrkacz et al, 1984; Crelling et al, 1988) have separated coal macerals using a modified medical technique called Density Gradient Centrifugation (DGC). This technique is considered unsuitable for use in pulverised fuel experiments for a number of reasons.

1) Comminution of coal feed down to approximately 1 to 3 microns average size is required for good separation, while the smallest macerals defined in Australian Standard 2856 are inertodetrinite, at 3 to 30 microns, and micrinite at less than 2 microns.
2) In order to use density as a separation criterion, the coal must first be demineralised using HF and HCl, and in separating the density fractions the finely ground coal is centrifuged in CsCl, using a non-ionic dispersant. Both of these treatments have potential for marked effects on surface chemistry of such finely comminuted particles.

Curragh Concentrates

Different maceral groups form preferentially in different environmental conditions in the coal swamp, and changing conditions are recorded by the bands composed of different coal lithotypes seen within a coal seam.

In order to generate quantities of sample large enough to feed to a laboratory scale furnace, samples of six lithotypes were taken from the opencut face at Curragh Queensland Mining Ltd., Blackwater, and were further handsorted before being prepared into a 63-90μm fraction by hammer mill and sieve. The lithotype concentrates were selected according to conventional geological logs of the coal face which divide the coal into 6 categories as shown below.

Bright	**> 90% bright coal**
Bright Banded	**60-90% bright coal, 10-30% dull bands**
Banded	**40-60% bright, 30-70% dull coal -interbanded**
Dull Banded	**60-90% dull coal, 10-30% bright bands**
Dull	**> 90% dull coal**
Fusain	**fibrous coal**

Tables 1 and 2 show the maceral and microlithotype purities of these fractions from Curragh coal. The Bright and Dull lithotypes achieved 96-97% purity of vitrinite plus liptinite, and inertinite macerals respectively. Further purification was found to be necessary for the Fusain fraction, which consists of fossil charcoal formed in thin bands or lenses as a result of bushfires or intense oxidation of exposed vegetable matter. Separation of Curragh fusion was performed by hand sorting the +1mm fraction using a stereomicroscope, and also on the basis of shape factor using a miniature shaking table.

Banded and Dull Banded lithotypes most closely approach the 1:1 ratio of bright to dull coal, but with a greater proportion of vitrinite in Banded, and more semifusinite in Dull Banded coal. Dull coal has relatively high proportions of all important inertinite macerals - semifusinite, inertodetrinite, macrinite and fusinite in descending order. Fusain, on the other hand, has almost exclusively fusinite and semifusinite in almost equal quantities, with about 11% vitrinite impurity.

Morphometric Analysis

Four of the six Curragh concentrates as well as whole Curragh coal have so far been analysed. The particles were imaged down a reflected light microscope and viewed on a video monitor with resolution of 512 by 512 pixels. At least 500 points were counted per char sample, on a grid basis using a mechanical stage.

The morphometric analysis was carried out by tracing each new char particle by "mouse" on a digitising pad. This enables several parameters to be measured simultaneously:

1) Area - A1 - total area of traced and filled object
2) Longest Dimension - L.D. - longest dimension of an object
3) Perimeter - P1 - the perimeter of a traced object
4) Shape Factor - S.F. - numerical calculation of the sphericity of an object using the formula :

$$S.F. = 4pA / p^2)$$

where A = area, p = perimeter

In addition to this, by thresholding the grey levels of each new char particle, only the char material, with its thin walls and varying anisotropy, may be highlighted. An area measurement of this field allows the recording of other useful features:

5) Area - A2 - area of char material only, excluding vesicles.
6) Porosity - P - calculation of % porosity of each char particle using the formula :

$$P = ((A1 - A2) / A1) \times 100$$

As well as these measurements, the char type of each particle is recorded in an attribute array as a code number from 0 to 21 . Table 3 gives a tree diagram which can be used to quickly identify char type.

Char Parameters

Table 4 shows the mean values and (in brackets) one standard deviation each side of the mean of the chief parameters of char particles from the five char concentrates analysed.

The characteristics illustrated here apply to a Gondwana coal of the Bowen Basin, QLD, with mean random telovitrinite reflectance of 1.23%. This places this coal in the prime coking range, although it has been washed to remove the premium coking fraction and has about

Maceral	Bright	Bright Banded	Banded	Dull Banded	Dull	Fusain
telovitrinite	61.3	39.8	29.0	21.3	0.7	5.0
detrovitrinite	33.3	42.9	26.4	22.8	1.4	6.0
sporinite	0.5	0.8	0.2	0.2	0.7	0.0
cutinite	0.5	0.3	0.3	0.2	0.3	0.0
resinite	0.3	0.2	0.0	0.1	0.0	0.0
micrinite	0.4	1.7	1.6	0.6	0.0	0.0
macrinite	0.1	1.3	6.0	3.1	13.9	0.4
semifusinite	0.7	6.8	27.1	41.1	47.7	40.0
fusinite	0.3	3.3	3.2	5.5	12.2	45.3
inertodetrinite	0.1	1.4	4.4	4.0	21.7	1.5
minerite	2.4	1.5	1.8	0.8	1.4	1.8
General						
vitrinite	94.6	82.7	55.4	44.1	2.1	11.0
liptinite	1.3	1.3	0.5	0.5	1.0	0.0
inertinite	1.6	14.5	42.3	54.6	96.9	87.2

Table 1: Percentage Maceral Content of Curragh Lithotype Concentrates

Microlithotype	Bright	Bright Banded	Banded	Dull Banded	Dull
vitrite	69.3	60.7	27.0	17.6	1.3
clarite	15.9	7.4	0.7	0.7	0.0
vitrinertite-V	8.5	16.5	25.6	17.4	0.8
vitrinertite-V=I	0.3	0.7	7.3	6.3	0.3
vitrinertite-I	0.3	2.7	17.6	22.0	1.6
duroclarite	2.0	4.3	4.6	6.0	0.0
clarodurite	0.1	0.0	0.5	1.2	0.1
vitrinertoliptite	0.1	0.0	0.5	0.0	0.0
durite	0.0	0.0	0.1	2.5	5.8
semifusite	0.4	3.4	11.9	22.1	40.3
fusite	0.3	3.6	3.9	3.8	7.8
macrite	0.0	0.0	0.0	0.2	10.6
inertodetrite	0.0	0.0	0.0	0.1	30.6
minerite	2.8	0.7	0.3	0.2	0.8
General					
Vitrinite-rich	95.3	87.8	60.5	43.3	2.3
Inertinite-rich	1.9	11.5	39.2	56.6	97.0

Table 2: Percentage Microlithotype Content of Curragh Concentrates

POROSITY %	VESICLES PRIMARY	VESICLES SECOND.	WALL microns	SHAPE ROUNDED	SHAPE ANGULAR
70 - 90	1 - 3	common	< 5	tenuisphere	
			>5	crassisphere	
	---	many	<5		tenuinetwork
	variable	variable	var	mixed porous	mixed porous
60 - 70	1 - 3	common	>5	crassisphere	
	---	many	>5		crassinetwork
	variable	variable	var		mixed porous
50 - 60		>3	>5	mesosphere	
	---	many	>5		crassinetwork
	variable	variable	var		mixed
40 - 50		>3	>5	mesosphere	
	variable	variable	var		mixed
5 - 40		>3	>5	inertoid	mixed dense
					inertoid
	---	---	solid		solid
	inherited		solid		fusinoid
> 50% mineral matter					mineroid
particles <10um in size					fragment

Table 3: Tree Diagram for Char Type Identification

61% inertinite content. The trends which are noticeable are:
1) Porosity generally decreases from Bright char through to Fusain char, probably as a function of decreasing volatile matter content. Porosity varies on a much greater scale than volatile content - because vitrinite-derived chars also swell under the pressure of volatiles released within the char skin, and so increase their diameter considerably over the p.f. diameter.

2) Porosity of Banded and Dull char is very similar in range and mean - despite a great difference in petrographic content. Obviously, Dull coal (rich in semifusinite, inertodetrinite, macrinite and fusinite) is not inert in high temperature pyrolysis conditions, but releases volatiles to form char with a mean porosity of 51.6%.

3) Porosity of Bright char is highest in both mean and range, while Fusain char is lowest in both mean and range, while Curragh whole char has an intermediate porosity, slightly higher in mean and range than the Banded and Dull values.

4) On a similar trend, the mean values of A2 or highlighted char area, increase from Bright char to Fusain char, indicating there is more char mass per particle to burn.

5) Perimeters of filled, traced particles are very similar for the Bright, Banded and Dull fractions in both mean and range. However, Fusain char has a larger range and a larger mean than all the rest. This indicates that relatively there are some very small fragments in Fusain char, but that the large particles are considerably bigger than those produced by the other chars.

6) Shape Factor or sphericity of the Whole, Bright, Banded and Dull chars are quite surprisingly similar in mean and range, varying only between 0.59 and 0.62. However, Fusain char again shows its different characteristics with a sphericity almost half the other values at 0.32. This indicates that Fusain does not fuse at 1500°C, but retains its angular shape, or breaks into smaller angular fragments.

7) Individual Distance (or greatest length) measurements show an irregular trend. Banded char has the smallest mean length and the lowest range. Bright char has a greater diameter and higher range, presumably because of its greater tendency to swell due to higher volatile content. Fusain char has a similar mean length to Bright char, but this is obviously not due to swelling but to retention of its original form. Its range is larger than for Bright char, indicating there is a greater variety of material from fragments of 28µm to particles over 106µm. Dull char has the greatest mean diameter of all the concentrates analysed. Despite lower volatile content than Bright and Banded, Dull has the ability to swell and remain largely intact, while Fusain char, owing to its more angular and brittle inherent form, tends to break up and thus reduce its mean diameter. Original mean p.f. size must be compared to mean char size to determine whether grind characteristics are responsible for the variation in mean longest dimension.

8) Char type is merely a code number for the main type of char produced by any fraction. Since the char codes generally grade from low density char at the low numbers to high density char at the high

numbers, mean char type indicates an average density, and the mean values rise from 5.5 for Bright char to 13.6 for Fusain char. The ranges also rise in this order. Mean char type for whole coal is 8.1, which falls below but closest to the Banded lithotype. Whole and Dull char have the broadest range of char types.

9) Char type shows that Bright char contains almost 40% anisotenuispheres, about 11% anisocrassispheres, and about 17% mixed porous, all low density chars. The higher density chars formed from vitrinite are mainly anisomesospheres, mixed, anisoinertoid and mixed dense. The 2-4% of solid and fusinoid chars formed from Bright coal corresponds reasonably to the ~2% of inertinite dominated lithotypes in the feed. About 7% of network chars are formed from this coal.

Curragh Banded char consists of a more even distribution of char types, with about 16% anisomesospheres and mixed, 14% anisocrassispheres and anisoinertoids, 12% mixed porous and mixed dense, and 10% anisocrassinetworks and anisotenuispheres. Only about 5% solid and fusinoid chars arise from Banded coal.

Dull coal produces about 25% mixed 50:50 char, and about 50% total mixed char. Anisocrassinetworks constitute about 20%, anisoinertoids 11% and anisomesospheres about 6%. Minor tenuisphere, crassisphere, solid and fusinoid chars are produced. Fusain char is dominated by solid char (25%), fragments of solid char (22%), anisoinertoids (15%), fusinoids (7%) and anisomesospheres (6%). Minor teniuspheres, crassispheres, mixed, skeletal and isoinertoid chars are produced.

Curragh whole char is not dominated by any one char type but has quite a preponderance of medium density char and little solid and fusinoid char for a coal with ~61% inertinite. The most significant char types are anisocrassispheres, anisocrassinetworks, mixed, tenuispheres, mixed porous and anisoinertoids. Anisomesospheres, anisotenuinetworks, mixed dense and isoinertoids are also present to the extent of about 20% in total.

Burnout results for comparison with these analyses are currently being completed.

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	No. of Points	A1	A2	P	P1	SF	ID	LD	CT
Whole	505	6228	2301	57.9 (37.5-78.4)	341.4 (188-495)	0.59 (0.45-0.79)	N.A.	57.9 (37.1-78.6)	8.1 (2.8-13.4)
Bright	502	2351	56.8	69.9 (49.3-90.4)	208.9 (111.2-306.5)	0.62 (0.47-0.78)	66.2 (38.3-94.0)	34.8 (23.0-46.5)	5.5 (0.8-10.2)
Banded	501	2024	891	51.5 (33.8-69.2)	201.9 (118.6-285)	0.60 (0.43-0.78)	55.2 (25.6-84.8) (440 pts)	35.5 (23.7-47.3)	8.8 (4.4-13.0)
Dull	501	2267 (240 pts)	1061 (240 pts)	51.6 (35.9-67.1)	217.5 (120.2-314.8)	0.61 (0.49-0.73)	75.6 (49.0-102.2)	33.9 (16.8-51.0)	10.3 (4.5-16.0)
Fusain	636	2459.7	1258.1	27.9 (3.5-52.3)	242.3 (13.2-471.4)	0.32 (0.09-0.55)	67.29 (28.26-106.3) (135 pts)	44.7 (15.0-74.4)	13.64 (8.98-18.3)

Table 4: Mean Values of Char Parameters

KEY:
A1 Total Area
A2 Char Area
P Porosity
P1 Perimeter
SF Shape Factor
ID Max. Length
LD Longest Dimension
CT Char Type

THE RADIO IMAGING METHOD – CASES AND CAPABILITIES

S. THOMPSON
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ABSTRACT

The Radio Imaging Method (RIM) is a remote sensing technique which utilises radio waves to detect geological problems in an un-mined block of coal. Critical factors impacting on RIM performance are the conductivity contrast between coal and its surrounding strata, existence or otherwise of seam barriers, seam thickness and operating frequency employed. Recent RIM surveys in Australia have demonstrated the techniques sensitivity to a wide range of geological features including seam rolls, dykes, faults and thinning coal. Current research includes the modelling of geological response to RIM signals, improved tomographic techniques and using RIM from horizontal and vertical boreholes.

1 THE RADIO IMAGING METHOD

The Radio Imaging Method (RIM) is a geophysical technique which uses medium frequency (100 - 520 kHz) radio waves to evaluate subsurface geology.

RIM relies on propagating radio waves through layered strata, such as a coal seam. The resulting EM wave signal will attenuate (lose strength) as a direct response to variation in the conductivity of the strata.

A RIM survey is conducted in a transmission mode between a transmitter and receiver through a coal block. It may also be used in transmission mode between boreholes and borehole to mine. The equipment is light and portable and certified intrinsically safe.

In an Australian in-mine survey, it is usual for a low cost direct ray survey to be conducted first in order to determine the presence or absence of seam disruptions. More detailed diagonal ray surveying and creation of a tomographic image only follows if the initial reconnaissance survey delineates an anomaly.

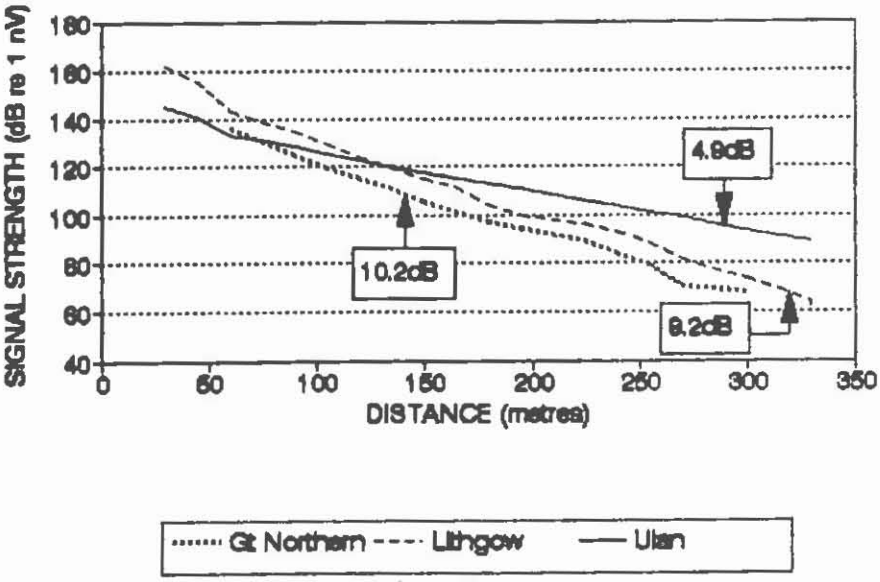
2 CONCEPTS IN RIM TECHNOLOGY

2.1 Signal Attenuation

Attenuation is defined as 'to reduce in force or value'. The attenuation rate of an EM signal in coal is established from a preliminary *calibration survey*, which establishes the normal rate of signal decay for a particular coal seam.

The rate of decay over an arbitrary distance (100 feet is chosen in order to maintain consistency with US results) is referred to as the attenuation rate. The *lower* the attenuation rate the *greater* the range of the RIM signal. Some examples from Australian coal seams indicate typical variability in attenuation rates (Fig. 1).

Fig.1 : RIM Signal Decay
Australian Coal Seams



Geological investigation requires maximising the operating range and the interaction of the propagating EM wave with changes in the electrical properties of the natural rock media (Stolarcyk, 1989). In geological investigations *high* attenuation paths are a clear indication of abnormal geology.

2.2 Operating Range and Interpretation

The factors affecting the operating range of a RIM signal are linked to the concept of attenuation rate. They are:-

1. *The contrast in conductivity between the coal and its surrounding strata:* Less contrast implies more heat loss as the signal travels through the coal and *increased* signal attenuation.

2. *Barriers to coal seam continuity:* i.e. sills, dykes, faults, washouts, rolls, seam thinning etc. The EM wave is reflected off the structure or otherwise 'lost' - the result - a weak or no signal at the receiver i.e. *increased* signal attenuation.

3. *Seam thickness:* generally the thicker the seam, the greater the operating range and *lower* the attenuation rate.

4. *Operating frequency:* a low frequency signal (100 kHz) will travel further than a high frequency signal (500 kHz). The trade-off is an accompanying loss of resolution power with range gain. Present underground RIM equipment transmits a 300 kHz signal.

Since the last factor is a constant all variability in attenuation rates encountered in a RIM survey can be attributed to a combination of the first three factors. Also, as the calibration survey provides a good control on the roof/floor to coal conductivity contrast in normal coal, then variability is essentially a consequence of *seam thinning or geological barriers*. However, seam barriers may themselves impact on the bulk conductivity contrast between the coal and its surrounding strata.

Having established that attenuation rate change is essentially a response to geology then the quality of interpretation remains a function of the mine geologist's understanding of the local geological environment and the intensity of RIM coverage in any particular survey.

3 RECENT CASES OF RIM IN AUSTRALIA

3.1 Wallarah Colliery

The RIM technique was trialled at Wallarah chiefly to evaluate the method's response to seam rolls in the Great Northern Seam. In addition, trials were conducted over a dyke and a fault in the workings.

The RIM technique was trialled at Wallarah chiefly to evaluate the method's response to seam rolls in the Great Northern Seam. In addition, trials were conducted over a dyke and a fault in the workings.

The RIM response, expressed as an attenuation rate, was found to be around 9-10 dB/100 feet for 'clear' coal.

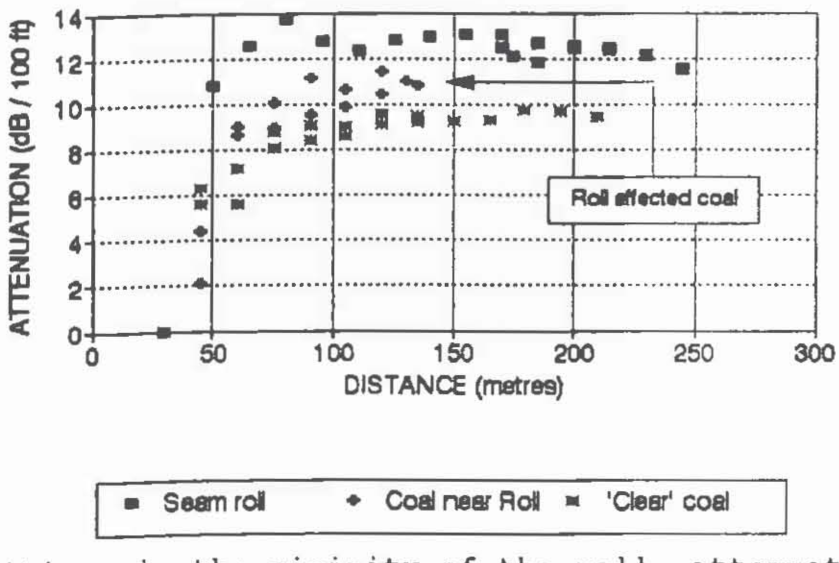
Seam rolls

The seam rolls at Wallarah are essentially compactional features which result in localised steep seam dips, some reduction of seam height and associated difficult roof conditions. Compaction is probably a response to differential dewatering of the strata overlying the Great Northern Seam and is caused by palaeochannel systems in the roof. Rolls are very localised features, and are difficult to predict in linear extent (along the axis of the associated palaeochannel).

The response to the RIM signal (Fig. 2) indicates attenuation rates ranging from 12-14 db/100 feet through the roll. Clear coal is indicated by attenuation rates less than 10 db/100 feet.

Fig.2 : Attenuation Contrast-Seam Roll

Wallarah Colliery



In addition, in the vicinity of the roll, attenuation rates in the surrounding coal are higher than in the 'clear' coal areas. This is almost certainly a response to changing roof conditions (due to sedimentological factors) which are having an effect on the overall roof/floor to coal conductivity system. Here, RIM is detecting subtle changes in the roof that are not obvious from a visual underground inspection.

The implication for the management of the colliery is that RIM provides an impartial means of evaluating an un-mined coal block for the presence or absence of these features. The RIM trial proved the technique is sensitive to seam rolls and the accompanying changes to roof strata associated with their occurrence.

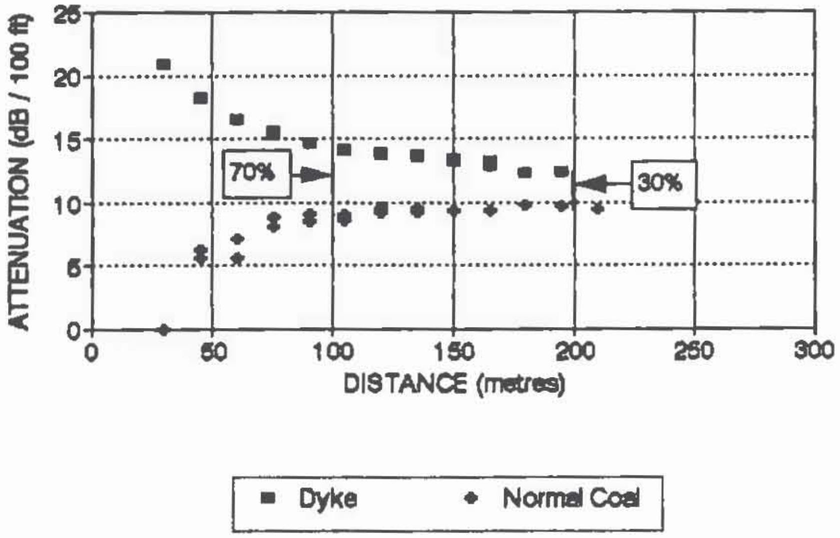
Dykes

A 0.8 metre thick altered dolerite dyke was chosen for the test work. It was decided to intersect the dyke at 90 degrees to its strike. This orientation minimises the expected RIM response and enabled a 'worst case' assessment of the method to be evaluated.

The results indicate that even a dyke < 1 metre in thickness at Wallarah has an attenuation rate which is 30% higher than the surrounding coal at 200 metres Transmitter (Tx) to Receiver (Rx) separation. At 100 metres separation the attenuation rate through the coal will be 70% higher (Fig. 3).

Fig.3 : Attenuation Contrast-Dyke

Wallarah Colliery

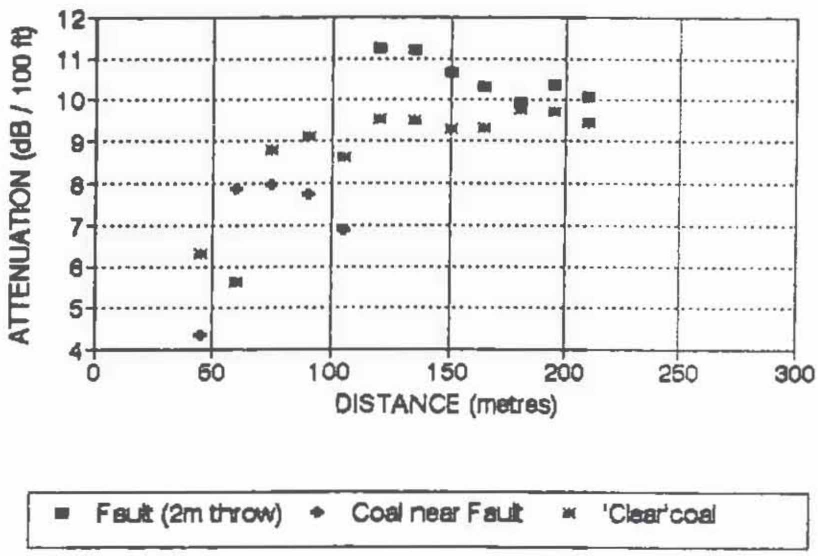


Faults

A normal fault (2 metre displacement) was also tested for RIM response. Here attenuation rates are higher than the surrounding coal by about 25% at 200 metres Tx to Rx separation and 40% at 100 metres separation (Fig. 4).

Fig.4 : Attenuation Contrast-Fault

Wallarah Colliery



3.2 Angus Place Colliery

At Angus Place Colliery the target was quite different. Concern was raised over the likely thickness of coal over a longwall panel. RIM was used to provide a quantitative predictive model of seam thickness for the longwall. A relationship was established using RIM attenuation values and measured sections of the seam in the gateroads.

This work has since been followed up as mining has proceeded. The RIM prediction of thickness is consistently closer than the only other pre-mining option, that is, averaging the maingate and tailgate measured seam thicknesses (Table I).

TABLE I

ANGUS PLACE COLLIERY

Follow-up on RIM prediction

	Survey 1	Survey 2	Survey 3
Av. measured seam th.(m) -	2.29	2.35	2.54
RIM predicted seam th.(m) -	2.28	2.30	2.40
Av. of gateroads seam th.(m) -	2.16	2.22	2.33

In this case the RIM signal has predicted the average thickness along the wall to an accuracy of 0.1-0.2 metres.

4 RIM RESEARCH

Currently, RIM research is geared towards upgrading the present RIM I system (which measures signal amplitude only) to the RIM II system, which measures amplitude and signal phase change.

The RIM II system will enable tomographic imaging of the strata from vertical and horizontal boreholes. The latter is the subject of an existing NERDDC funded research programme involving ACIRL and STOLAR Inc. of the United States.

The NERDDC work includes the mathematical modelling of geological response to RIM through Macquarie University and improved methods of tomography (CSIRO).

5 CONCLUSIONS

1. The Radio Imaging Method is a simple, cost effective technique for establishing the presence or absence of geological features in an un-mined coal block.

2. RIM has a proven response to seam rolls, dykes, faults and seam thinning in Australian conditions.

3. Long term cause and effect studies at an operation offer obvious benefits:-

    * to the mine geologist's predictive 'toolbag'.

    * to management, enabling better planning decisions to be made.

4. Research in RIM is geared to extending the range of RIM applications and improving geological interpretation.

6 ACKNOWLEDGEMENTS

I would like to thank the respective management and staff of Coal and Allied Operations Ltd., Wallarah Colliery, and NEWCOM Collieries, Angus Place Colliery for their permission to publish results from RIM work in their mines.

John Edwards of Coal and Allied kindly helped on all Wallarah RIM surveys even when the 'going got tough' (and wet).

I acknowledge Larry Stolarcyk of Stolar Inc. (USA) for providing volumes of theoretical material on RIM technology.

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A GEOPHYSICAL STUDY OF THE GUNNEDAH BASIN, NEW SOUTH WALES

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INTRODUCTION

The Gunnedah Basin represents an important central part of the Sydney-Bowen Basin. The Permo-Triassic rocks of the basin are overlain unconformably to the west by the Cretaceous and Jurassic rocks of the Great Australian Basin. To the east lie the folded Carboniferous and Devonian rocks of the Tamworth Synclinorial Zone bounded by the two major thrusts - the Hunter-Mooki Thrust and the Peel Fault. Further east lies the Woolomin-Texas Block belonging to the New England Fold Belt.

Whilst the major gravity features of the area have been known for over 20 years it is only in the last few years that a complete aeromagnetic coverage of the area has become available. It is opportune therefore to present a brief preliminary interpretation of the main magnetic anomalies in conjunction with the gravity features.

Variations in density and magentization of rock units produce gravity and magnetic anomalies. The definition of these anomalies depends upon the spacing at which measurements are made. Small and shallow sources produce short-wavelength anomalies and therefore require close measurements for their detection. The aeromagnetic data presented here were acquired by the NSW Geological Survey and the BMR at a spacing of 60 m along east-west flight lines flown 1500 m apart at a ground clearance of 150 m. The general structural trend being northerly in the area, no significant magnetic sources are likely to be missed. On the other hand the gravity data (acquired mostly by the BMR) are spaced at 11 km except in some parts where the spacing is closer. Although major features of the gravity field are recorded within this data, smaller variations associated with shallow sources are missed. Furthermore, variation in magnetization of rocks normally has a very wide range whilst the variation in density lies within a narrow range. Thus short-wavelength anomalies with a large variation in amplitude represent the norm over areas where igneous rocks lie at a shallow depth.

MAGNETIC FEATURES

The residual total Magnetic Intensity (T.M.I.) data for the six 1:250,000 sheets of Narrabri, Manilla, Gilgandra, Tamworth, Dubbo and Singleton are presented as a grey-colour image in Fig. 1a and selected profiles in Figs 2 & 3. Apart from isolated anomalies in the eastern part of the area and the very significant anomaly along the Peel Fault, the image defines a broad zone of magnetic disturbance that overlies the Carboniferous rocks in the western part of the Tamworth Synclinorium, the Hunter Thrust and the Gunnedah Basin. Within this zone, a strong linear anomaly stands out along a large part of the Hunter Thrust.

The high amplitude magnetic anomalies along the Peel Fault are produced by the serpentinite masses that crop out not only along the fault but also branch out obliquely to it (locality no. 1 & 2 in Fig. 1b). Most solutions of these anomalies yield thick dyke sources; at 3 the calculated thickness is larger than the width of the outcrop, suggesting a wedge-like source rather than a sheet-like. At 4 the anomaly strikes along a gentle arc convex to NE for a length of 20 km with a maximum off-set of 2 km from the trace of the fault-line.

On the western side of the Tamworth Synclinorium, two linear gradient zones parallel the flanks of the Rocky Creek Syncline (5 & 6 in Figs 1 & 2). These zones merge at the closure of the northern section of the syncline (7). Farther south, the steepest part of this merged zone follows the contact between the Luton and the Baldwin formations. It is likely that these zones are related with faults belonging to the Kelvin Fault System. The Hunter-Mooki Thrust probably follows the western gradient zone, north of Mt. Kaputar.

Hunter-Mooki Thrust

A pair of linear anomalies lying along a gentle arc more than 50 km in length, south of Mount Kaputar, mark the inferred location of the Hunter-Mooki Thrust (8). The anomalies look like a pair of strings of beads on a contour map, owing to their short wavelengths and the predominance of the antisymmetric component. Although Ramsay and Stanley (1976) fit dyke-like models to the anomalies, fault solutions applying a method due to Qureshi and Nalaye (1978) have also been obtained. The anomaly becomes broader further south and can be followed up to the Liverpool Range where anomalies due to the near surface Teriary Basalt and their feeder veins predominate (Fig. 3).

Ramsay and Stanley (1976) attribute the Mooki Thrust magnetic anomaly to plug like Warrigundi intrusives that occur to the east. The anomalies produced by the latter (9 to 12) are, however, roughly circular and well separated and do not resemble the long and narrow elliptical anomaly. It is most likely that the anomaly arises from the Boggabri Volcanics underlying the Maules Creek Sub-basin at a fairly shallow depth and faulted out against the Hunter-Mooki Thrust.

Other Magnetic Features

Anomalies at 13, 14 & 15 are produced by the Werrie Basalt faulted at the thrust. Roughly circular anomalies at 16 & 17 have no apparent surface source but may be associated with Warrigundi intrusives buried at a shallow depth . Anomalies at 18 and 19 occur over the Lochinvar Anticline and are probably produced by the Winders Hill Granodiorite. There are circular or broad elliptical anomalies at 20 to 30; the last five of which may be related with known granites, the others having no surface source. Intense magnetic lows at 31 to 33 are probably due to reversed magnetization.

Outcropping igneous rocks, chiefly Tertiary Basalt, Garrawilla Volcanics, Boggabri Volcanics and Werrie Basalt produce a mottled pattern of short wavelength anomalies (<4 km), owing to variability of magnetization, topographic relief and differential weathering (Figs 1 & 3). Extension of similar pattern over areas covered by Quaternary sediments is indicative of the presence of these rocks at a shallow depth.

A low-level magnetic disturbance associated with Tertiary igneous activity and a magnetic linear can be recognized in the region of the Mount Coricudgy Anticline. Anomalies in the south-western part of the area overlie the Molong High.

Magnetically quiet areas occur over the Bundarra Plutonic Suite, east of the Peel Fault, the eastern part of the Tamworth Synclinorium and the Hill End Trough.

GRAVITY FEATURES

The most prominent gravity features of the area are the three linear anomalies paralleling the western boundary of the New England Fold Belt. They are named by Darby (1969) as the Namoi Gravity High (NGH) that lies over the Tamworth Synclinorium, the Gwydir Gravity Low (GGL) that straddles the Hunter-Mooki Thrust and the Meandarra Gravity Ridge (MGR) that lies to the west over the Gunnedah Basin. These anomalies can be discerned in the 1976 BMR Gravity Map of Australia in northern New South Wales and for at least 100 km within Queensland (Qureshi, 1984).

On the basis of surface geology, it is valid to relate the NGH to the folded Devonian rocks of the Tamworth Synclinorium which are likely to be denser than the New England granite suites in the east and the Permo-Carboniferous rocks to the west (Bramall & Qureshi, 1984). Murray et al (1989) however, suggest that an underlying Carboniferous volcanic arc of mafic character (over-thrust by the Tamworth Belt) is a possible source. A study of rock densities and modelling of the anomalies may resolve the problem. The GGL may be associated with the Carboniferous rocks forming the Rocky Creek Syncline to the east and the younger Permian (and Carboniferous) rocks to the west of the Hunter-Mooki Thrust.

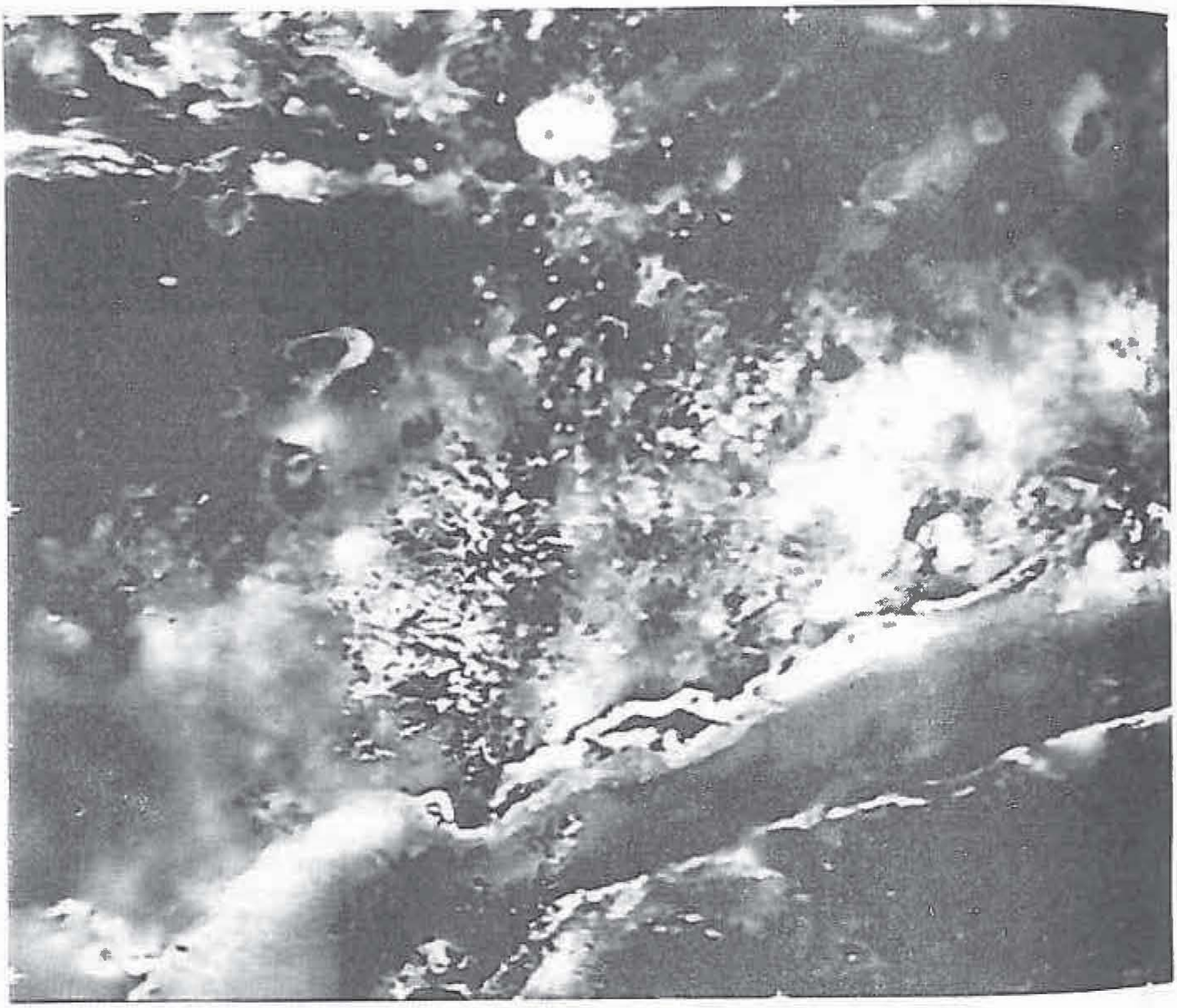

Fig. 1a. Grey-colour image of T.M.I. data based on pixel size of 500 m x 500 m. White to light grey shades represent positive and deep grey to dark shades represent negative anomalies. See Fig. 1b for locations of features described in the text.

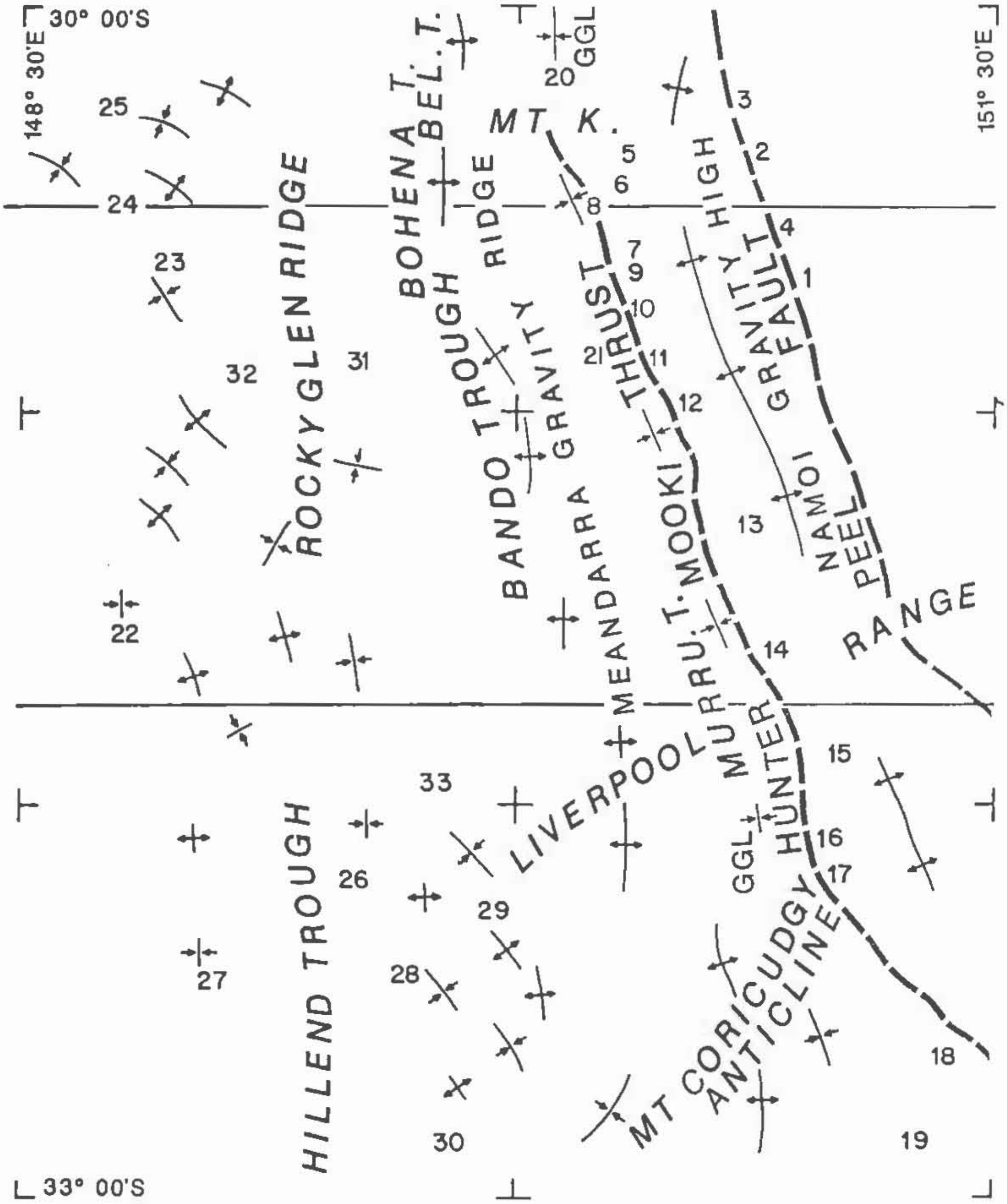

Fig. 1b. Numbered locations of magnetic features shown in Fig. 1a and described in the text. Axes of gravity highs and lows are shown by symbols used for anticlinal and synclinal axes respectively. Profiles shown in Figs. 2 and 3 are located. Abbreviations used: GGL - Gwydir Gravity Low; MURRU - Murrurandi; T - Trough; BEL - Bellata; K - Kaputar.

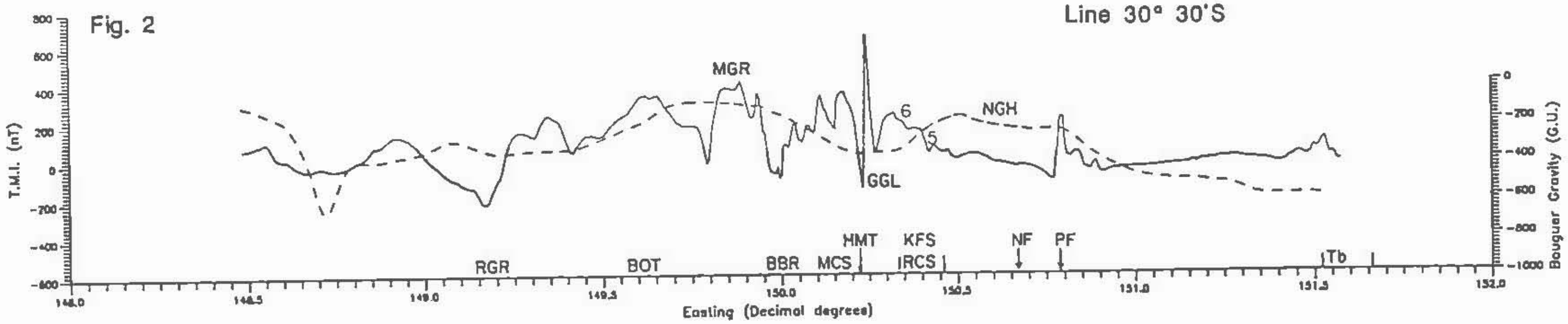
Fig. 2
Line 30° 30'S
MGR
NGH
GGL
6
5
RGR
BOT
BBR
MCS
HMT
IRCS
KFS
NF
PF
Tb
T.M.I. (nT)
Bouguer Gravity (G.U.)
Easting (Decimal degrees)

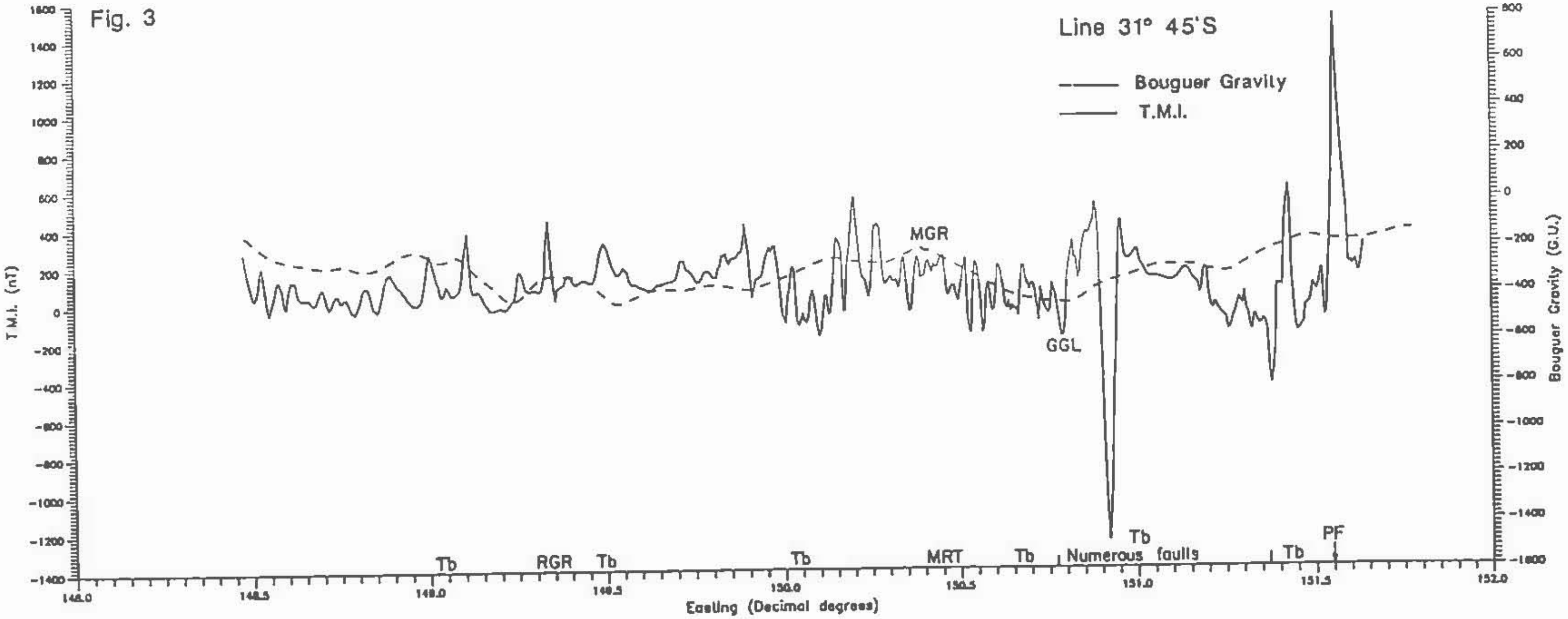
Fig. 3
Line 31° 45'S
Bouguer Gravity
T.M.I.
MGR
GGL
Tb
RGR
MRT
Numerous faults
PF
T.M.I. (nT)
Bouguer Gravity (G.U.)
Easting (Decimal degrees)

GEOPHYSICS OF GUNNEDAH BASIN

Meandarra Gravity Ridge

A high-pass filtering of the Bouguer anomalies in eastern Australia (cutting out wavelengths longer than 250 km) has enhanced short-wavelength anomalies in the region including the MGR (Murray et al, 1989). This feature can now be observed for a length of 1200 km as far north as $24^{o}S$. Although the feature looks continuous on the image in eastern Australia, the anomaly is formed by a series of gravity maxima placed next to each other. Small off-sets between the maxima give it a curvature (concave to the east between $29^{o}S$ and 32^{o} S) so that it runs parallel to the NGH. The maximum displacement of 40 km occurs along the Golburn River, north of $29^{o}S$ and south of $32^{o}S$, the feature is almost rectilinear and longitudinal.

No apparent source of the MGR can be discerned in surface geology. The gravity high over the Sydney Basin is one of the larger maxima that occurs along the MGR (over the Macdonald Trough), the high is accompanied by a coincident magnetic anomaly. The anomaly has been interpreted to indicate a large mafic body underlying the Sydney Basin within the upper crust (Qureshi, 1984); a reinterpretation has accommodated a small part of the source in the lower crust to provide a link with the mantle (Qureshi, 1989).

On the basis of drilling results in the Gunnedah Basin, Tadros (1988) has delineated several troughs separated by structural highs. The axes of gravity maxima lie generally 15 to 20 km east of the axes of the troughs but an amazing one to one correspondence suggests an inherent relationship between them. The magnitudes of these maxima range between 200 and 250 G.U. (c.f. 440 G.U. over the Macdonald Trough).

Other Gravity Anomalies

Within the GGL there is a local gravity high at 20 coincident with a large magnetic anomaly indicating a probable common mafic source. In the area west of the Gunnedah Basin there are several local gravity highs and lows, some of the latter are associated with magnetic anomalies suggesting probable granitic sources (22, 23, 25 & 26).

Figs. 2 & 3. T.M.I. and Bouguer anomaly profiles. Abbreviations used are:

RGR	Rocky Glen Ridge	KFS	Kelvin Fault System
BOT	Bohena Trough	RCS	Rocky Creek Syncline
BBR	Boggabri Ridge	PF	Peel Fault
MCS	Maules Creek Sub-basin	NF	Namoi Fault
HMT	Hunter-Mooki Thrust	MRT	Murrurandi Trough
		Tb	Tertiary Basalt

CONCLUSIONS

The Gunnedah Basin is characterized by a broad zone of magnetic anomalies produced by shallow igneous rocks, dolerite sills within the sedimentary section and basal volcanics.

The maxima comprising the Meandarra Gravity Ridge generally have a one to one correspondence with the troughs consistituting the basin suggesting an inherent but indirect relationship. As for the Sydney Basin, the gravity ridge has a sub-basin source.

ACKNOWLEDGMENTS

This paper is published with the permission of the Director-General of the Department of Minerals and Energy.

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EXHALATIVE MINERALS DERIVED FROM COAL AND ASSOCIATED KAOLINITIC STRATA AT BURNING MOUNTAIN, HUNTER VALLEY, NSW

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University of New South Wales

SUMMARY

A rare suite of exhalative minerals are presently being deposited on the surface of Burning Mountain near Wingen, New South Wales. These minerals are a result of the combustion of subterranean coal seams, believed to have been burning continuously for many thousand of years. The exhalative minerals which have been identified include

native selenium Se
native sulphur S
salammoniac NH_4Cl
millosevichite $Al_2(SO_4)_2$
alunogen $Al_2(SO_4)_3.17H_2O$
jarosite $KFe_3(SO_4)_2(OH)_6$
potassium alum $KAl(SO_4).12H_2O$
tschermigite $NH_4Al(SO_4).12H_2O$
yavapaiite $KFe(SO_4)_2$
unnamed anhydrous potassium alum $KAl(SO_4)_2$ and
unnamed anhydrous ammonium alum $NH_4Al(SO_4)_2$

The elemental constituents of these minerals have either been derived from the burning coal and associated mineral matter or leached from the adjacent kaolinitic country rock.

INTRODUCTION

Burning Mountain near Wingen in the upper Hunter Valley of New South Wales (Fig. 1) is a geological curiosity where the natural, subsurface combustion of coal seams is currently taking place. Based on the current rate of advancement of the fires, the phenomenon has proceeded probably continuously for more than 15,000 years (Loughnan and Roberts, 1981). The coal seams, which form part of the early Permian Koogah Formation, have been explored to a limited extent only and little is known of their number, thicknesses or specific properties. Nevertheless, coal of the same age, in the lower Hunter Valley; Greta Coal Measures, is renowned for its relatively high volatile content and unusual concentrations of pyrite (David, 1907); characteristics that render it particularly susceptible to spontaneous combustion and conceivably a similar combination of properties has been responsible for ignition of the coal in the Wingen area. The lower part of the Koogah Formation at Burning Mountain comprises for the most part extraordinarily thick beds of kaolinite clayrock or flint clay which form the interseam strata (Loughnan, 1973) whereas a succession of lithic-quartz sandstones and conglomerates constitutes the upper part of the formation (Nicol, 1986).

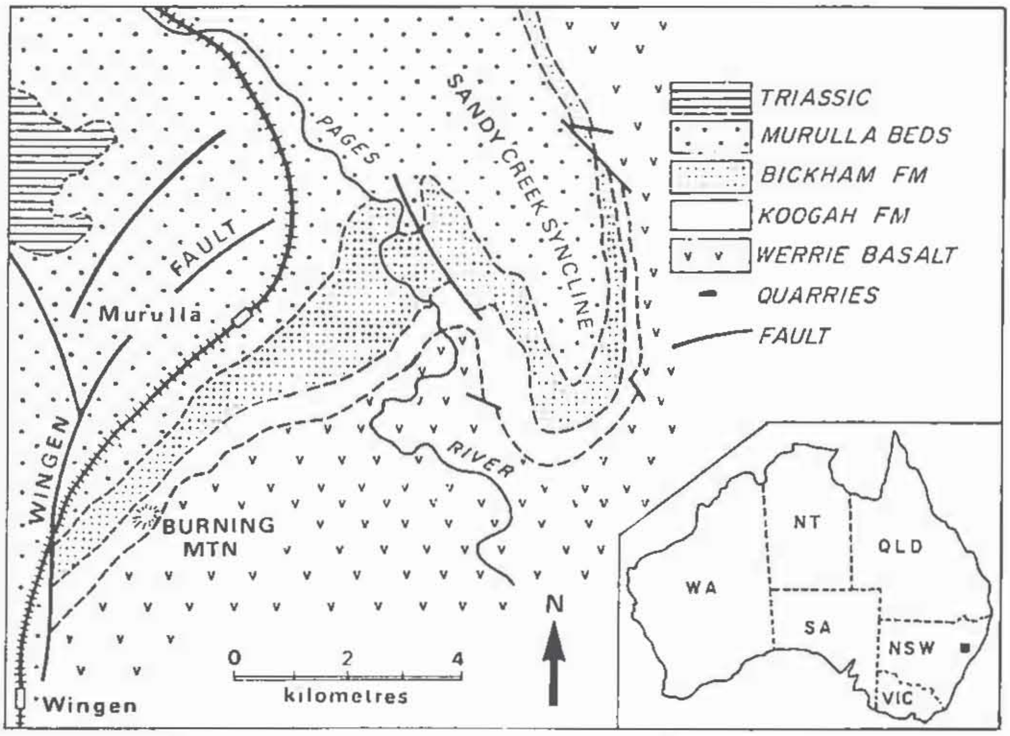

Fig. 1. Geological sketch map of the Burning Mountain area, N.S.W.

Faulting brought about by collapse of the strata above burnt out sections of the seams has led to development of fissures that, not only facilitate access of air to fan the fires, but furthermore provide avenues of escape for the volatiles and exhaust gases (Fig. 2). This unique phenomenon has led to the formation of a number of exotic exhalative minerals.

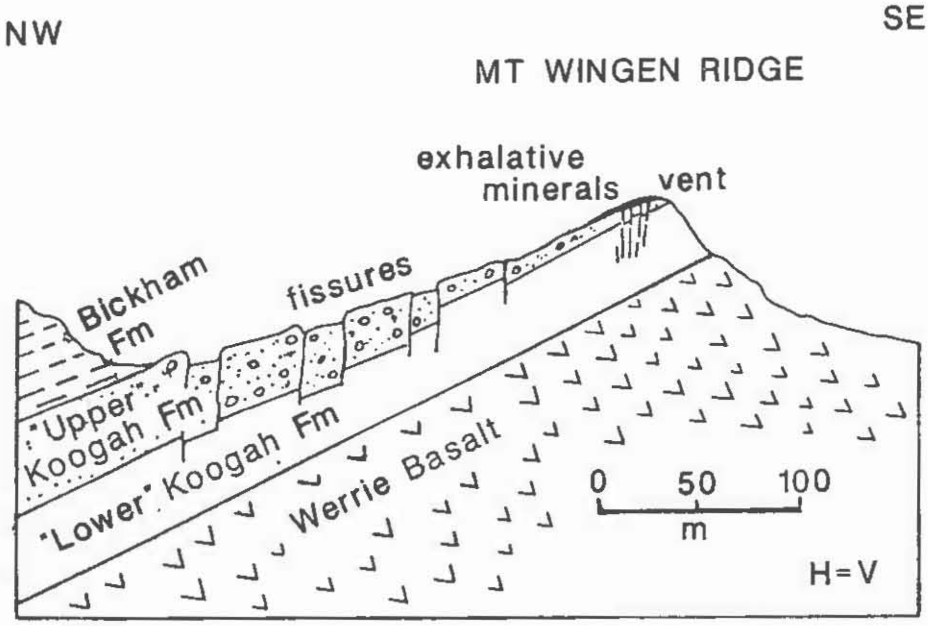

Fig. 2. Geological sketch of cross-section near Burning Mountain (after Rattigan, 1967).

EXHALATIVE MINERALS

Native Selenium and Sulphur

At Burning Mountain sulphur is the dominate sublimate being introduced into the overlying conglomerates and sandstones where it is reacting with aluminium, iron and potassium of the host rocks and also with ammonia contained in the exhaust gases to yield an array of sulphate minerals. Nevertheless, some elemental sulphur is also being deposited, typically as encrustations, in the uncombined orthorhombic form. Associated with it in parts of the area is native selenium which occurs as grey metallic acicular crystals, that are frequently hollow and tube-like, ranging in size from 0.005 mm to 0.5 mm. Qualitative analysis indicated only a minor to trace amount of sulphur within the native selenium crystals.

Salammoniac

Salammoniac is present as white skeletal and dendritic aggregates. Its restricted mode of occurrence is on the side of Burning Mountain, away from the zone of combustion, where it crystallized on the surface of organic matter, in particular twigs and leaves.

Sulphate Salts

A number of sulphate compounds are present at Burning Mountain. Minerals identified include jarosite, millosevichite, alunogen, potash alum, tschermigite and yavapaiite, as well as a number of previously unrecorded naturally occurring anhydrous alums with the theoretical chemical formulas of $KAl(SO_4)_2$ and $NH_4Al(SO_4)_2$.

Millosevichite and Alunogen

It is not possible to discriminate visually millosevichite from alunogen and identification is only possible by means of X-ray diffraction analysis. These aluminium sulphates are most abundant as incrustations often with a frothy-like appearance, although they are also present as earthy masses. Natural colour is white with a yellowish tint.

Millosevichite was reported by Srebrodol'skii (1974) to be insoluble in water, however samples of millosevichite from Burning Mountain, will hydrate to form alunogen if left in the atmosphere for a period of time. Initial X-ray diffraction analysis of many of the samples showed the presence of millosevichite, however after a period of time in the laboratory, exposed to the atmosphere, the same samples showed the presence of alunogen and the absence of millosevichite. In cold water millosevichite is slowly dissolved, however its solubility greatly increases in hot water.

Alunogen, as observed in thin section, is normally yellowish in colour, occasionally deep orange, and is typically fibrous of variable size, with a pseudo-concretionary distribution which often encloses an iron-rich core. Alunogen and millosevichite appear to have replaced the matrix of the host sedimentary rocks. Quartz and rare feldspar grains occasional show alteration features including an etch appearance. Fractures through the alunogen-rich portions are, as microscopically observed under crossed nicols, often lined with a deep blue-coloured fibrous material. This material may represent alunogen with a higher iron content, or alunogen with a higher water content.

Typical water content for alunogen found by Larsen and Steigner (1928) was 15.5 molecules, but they did stress that the water content is variable ranging from 12.5 H_2O to 18 H_2O. This variation in water content is possibly an explanation for the variation in optical properties observed for alunogen from Burning Mountain.

Anhydrous Salts

At Burning Mountain there exists an unusual series of isostructural anhydrous alums with the general formula of $(K, NH_4)(Al,Fe)(SO_4)_2$. The cations NH_4^+ and K^+ have similar radii; approximately 1.4 angstroms (Ross and Evans, 1965), hence it is not surprising that substitution for one another occurs in the crystal structure. Likewise, the ionic radius of Fe^{3+}; 0.67 angstroms is similar to the radius of Al^{3+}; 0.57 angstroms, which results in the substitution of the two ions. Of the anhydrous salts identified, only yavapaiite; $KFe(SO_4)_2$ has been recorded in nature.

In handspecimen, thin section and under the scanning electron microscope (SEM) the anhydrous alums appear similar, consequently differentiation of the anhydrous alums is difficult. Similar to millosevichite-bearing samples, anhydrous alum-bearing samples have an iron-rich core and normally fill the matrix between quartz and rare feldspar grains.

The anhydrous alums are fibrous in habit with a variable grain size. Fine interlocking fibres is the typical occurrence with occasional patches of coarse grained fibres. Small fibrous rosettes, maximum diameter 0.4 mm are also present. Observed crystals in samples rich in the anhydrous potash alum; $KAl(SO_4)_2$ show a tabular habit, occasionally with a branching cluster arrangement. Similar to the anhydrous potash alum, the anhydrous ammonia alum salt; $NH_4Al(SO_4)_2$ is tabular in habit and in cross section the crystals are pseudo-hexagonal in shape. In most samples examined using the SEM, delicate elongated crystals, sometimes forming small rosettes, are present possibly representing hydrated alteration products.

X-ray diffraction patterns and chemical analysis for a selected number of the salt-rich samples from Burning Mountain are shown in Fig. 3 and Table 1 respectively. The samples analysed did not constitute pure mineral specimens but samples containing a combination of salts. Sample A, which contains a high content of anhydrous NH_4-alum, correspondingly contains the highest NH_3 content of the samples analysed. Similarly, sample B and D, containing the highest K_2O contents, contain high proportions of anhydrous K-alum. The most unusual feature illustrated by the chemical analyses is the high iron contents, relative to the aluminium contents, and presumably the iron is present substituting for aluminium in all the salts including alunogen. It is most likely that there is a continuous series between the Fe-rich and Al-rich alums. However, for the substitution of NH_4^+ for K^+, a continuous series is not indicated by both the chemical and X-ray diffraction analyses; substitution probably occurs only on a limited scale. The silica content in the chemical analyses represent quartz within the samples.

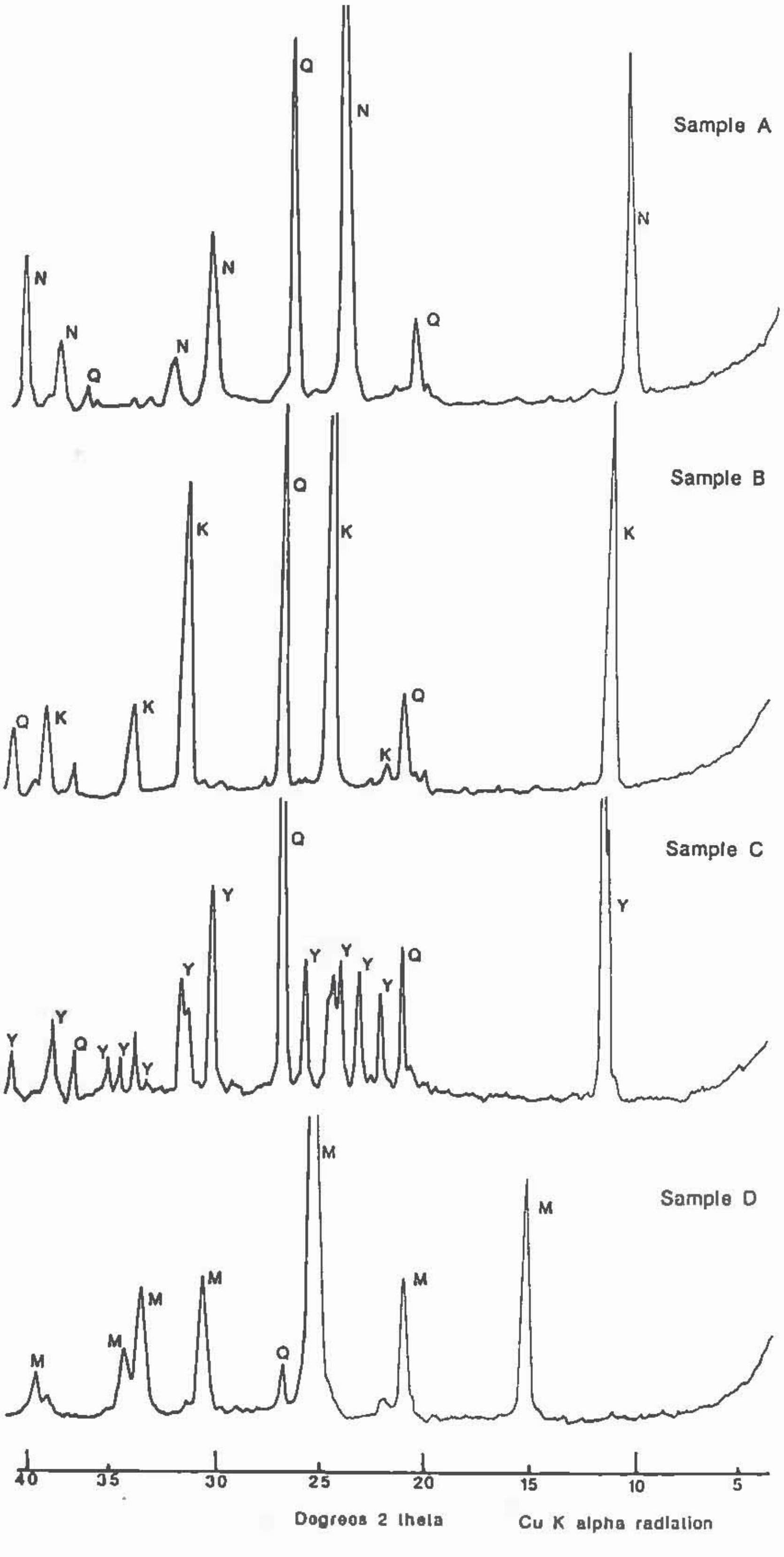

Fig. 3 X-ray diffraction scans of exhalative salts from Burning Mountain.

Table 1 Chemical analyses of sulphate-rich samples

	A	B	C	D
SiO_2	36.30	37.57	33.94	5.91
TiO_2	0.67	1.15	0.27	0.25
Al_2O_3	11.98	9.16	2.86	20.28
Fe_2O_3	4.73	5.95	15.24	9.21
MnO	0.01	0.12	0.13	0.05
MgO	0.14	0.14	0.11	0.32
CaO	0.12	0.21	0.05	0.08
Na_2O	0.17	0.20	0.11	0.59
K_2O	1.39	8.12	9.55	0.34
P_2O_5	0.18	0.85	0.05	0.13
SO_3	38.74	36.99	37.19	61.51
$(NH_4)_2O$	5.59	n.d.	n.d.	n.d.
Total	100.02	100.46	99.50	98.67

NOTE

A: $NH_4Al(SO_4)_2$ salt dominant, quartz abundant.
B: $KAl(SO_4)_2$ salt dominant, quartz abundant.
C: $KFe(SO_4)_2$ salt dominant, quartz abundant.
D: $Al_2(SO_4)_2$ salt dominant, quartz minor.

Total iron expressed as Fe_2O_3.
n.d. = not detected.
Analyst: Mrs Irene Wainwright, XRF Laboratory, Dept of Applied Geology, Univ. of NSW.

CONCLUSION

It is believed that the subterranean coal combustion at Burning Mountain is a similar phenomenon to a coal seam gasification process, where in front of the combustion zone is a pyrolosis zone in which the volatiles are released. Sulphur is liberated, forms sulphuric acid on the surface which then reacts with the country rock. The sulphate salts formed would initially be hydrated, however heat from the combustion zone would cause the hydrated salts to pass into an anhydrous phase. A review of the available literature indicates that Burning Mountain has a rare suite of exhalative minerals and is the only known locality containing natural anhydrous potassium and ammonium alums. These two minerals have not been formally named.

ACKNOWLEDGMENTS

Thanks are extended to our colleagues in the Department of Applied Geology, University of New South Wales, particularly Irene Wainwright for carrying out the chemical analyses and Rad Flossman for the preparation of excellent thin sections from extremely difficult samples. The assistance of Vera Piegerova School of Material Science University of New South Wales in the use of the scanning electron microscope is also acknowledged.

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GAS IGNITABILITY BY FRICTIONAL EFFECTS FROM AUSTRALIAN COAL MINE ROCKS

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INTRODUCTION

With the progressive reduction of risk from other sources, frictional effects involving rock strata (rock-on-rock or metal-on-rock) have come to represent one of the principal sources of methane ignition in modern underground coal mines. Such ignitions can arise, for example, when mining equipment comes into contact with roof or floor strata during coal extraction, and may even be possible from rock-on-rock or metal-on-rock collisions during roof falls.

A significant amount of research has been carried out on frictional ignition from sources involving metals, such as the interaction between aluminium and rusty iron or the behaviour of the different materials used in coal cutting equipment against a particular rock type, and considerable advances have been made in improving the design of continuous miners and longwall shearers to reduce frictional ignition risk. Little is known, however, of the relative propensity of the rocks themselves, particularly those in Australian collieries, to ignite explosive gas mixtures from frictional effects.

Following one of the recommendations arising from the enquiry into the explosion at Moura in 1986, and with the support of the National Energy Research Development and Demonstration Program, a project was initiated in 1987 to investigate the ability of different rock materials from Australian coal measures to ignite explosive gas atmospheres by frictional processes. This project has the ultimate object of developing tests to evaluate the relative incendivity potential associated with the different strata in Australian coal mines, and of relating this potential, if possible, to other properties of the rocks concerned.

SPARK SHOWER TESTS

An initial series of experiments was conducted to investigate the heating phenomena associated with friction at relatively high speeds, based on pressing small rock samples against a synthetic wheel on a simple bench grinder installation. The behaviour of different rocks from Australian mines under these conditions was recorded on time-exposure colour photographs, and a semi-quantitative classification developed based on their heat trail and spark-shower characteristics.

The results of these studies showed a significant variation in frictional behaviour, ranging from rocks which suffered rapid abrasion with no visible heating effects to rocks where sufficient heat was generated to melt the matrix (at least) and allow hot particles to be plucked out in a high-velocity stream. Both the hot-spot and the particle shower appear to be capable of acting as an ignition source. The test, however, does not necessarily represent the frictional conditions likely to be encountered in an actual mining operation, and is at best of use only in an initial sorting process.

FRICTIONAL IGNITION TEST RIG

In order to provide facilities for a more comprehensive investigation, a special rig was designed and built to evaluate the behaviour of different rocks under controlled conditions actually within in an explosive gas atmosphere. A rock or metal specimen (or slider) is pressed with a controlled force against a natural rock wheel, rotating at controlled speed in an enclosed gas chamber (Figure 1). One wall of the chamber consists of a thin plastic film, designed to rupture and dissipate the pressure generated should an ignition occur. Both the visible effects of the frictional contact and the time required to ignite the gas mixture are studied using video recording techniques.

Most of the tests for the present program are based on a slider and a rock wheel of the same material, allowing a range of samples from N.S.W. and Queensland collieries to be characterized in terms of their relative incendivity potential. Some preliminary tests have also been carried out with selected rock wheels and different continuous miner pick materials. A wheel diameter of 150mm has been used, run at speeds of 300, 500 and 700rpm to give contact velocities of 2.4, 3.9 and 5.5m/sec.

Tests using this facility have shown that the heat generated by rock-on-rock friction is sufficient, even at the lowest of these speeds, for some rock materials to ignite an explosive methane-air mixture (8.5% methane) in a remarkably short time. Other rocks, however, have been found to ignite the methane only at higher speeds, and some rocks do not ignite the methane-air mixture at any speed under the chosen test conditions.

INCENDIVITY CHARACTERIZATION

The behaviour of the materials at the different speeds, as seen from the video records of over 350 test runs, has been used to assign an "ignition category" to some 30 different rocks from eastern Australian coalfields in the current test program. The rocks tested are mainly sandstones, although some conglomerates, claystones and siltstones have also been included as well as a carbonate concretion and some igneous rock specimens. The requirement that the rocks be able to form a 150mm wheel (cut in the laboratory by a diamond coring bit) precludes soft or excessively jointed rocks from the test, but such materials would probably have an inherently low ignition category in any event.

Rocks in the test program have been characterized on a scale from 1 (no ignition at any of the above speeds) to 5 (ignition at all three test speeds). A statistical evaluation is currently in progress to relate this ignition category to the results of the spark-shower tests, and also to relate both the gas-chamber and spark-shower results to the mineralogical and geotechnical properties of the rocks concerned.

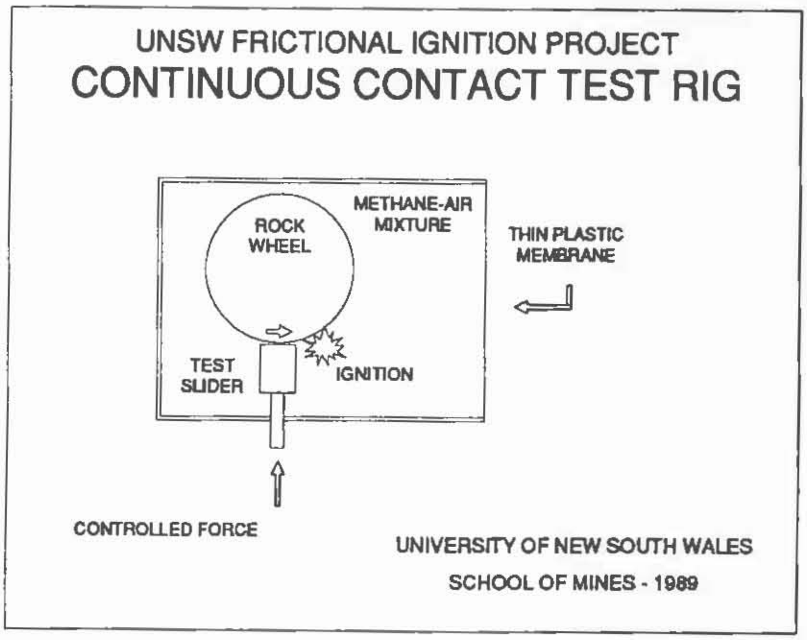

Figure 1. Schematic diagram of ignition test rig.

PHYSICAL AND CHEMICAL CONSIDERATIONS IN THE CONJUNCTIVE USE OF THE TOMAGO SANDBEDS AQUIFER FOR MINERAL SANDS MINING AND GROUNDWATER HARVESTING

S.R. JONES, R.J. CARR & M.J. THOM
D.J. Douglas & Partners

1. INTRODUCTION

This paper briefly reviews the available hydrogeological characteristics of the Tomago Sandbeds, and the observed effects on the aquifer resulting from the sometimes conflicting utilisation of the natural resources.

The area known as the Tomago Sandbeds lies on the northern side of Newcastle Harbour and forms part of a large coastal aquifer system which also includes the North Stockton Sandbeds and the Anna Bay Sandbeds (see Fig 1).

The Tomago Sandbeds is broadly defined by the pump station layout in Fig 1 and comprises an inner barrier dune system deposited during the late Pleistocene age. The area extends over 30 km in length, trending north-east, and is 2 to 5 km in width. The average depth of the aquifer in the developed area is 15 to 20 metres.

The topography of the sandbeds is low to moderate relief, with ground surface levels generally in the range RL 6m (AHD) to RL 10m, with isolated dune systems up to RL 40m: the most notable being Duckhole Dune in the vicinity of the RAAF Radar Station.

The area contains a number of major natural resources including: groundwater which is harvested as one of three main water sources for the Newcastle area; and heavy mineral sands including rutile, zircon, ilmenite and monazite which are extracted predominantly by dredging.

The Hunter Water Board (HWB) are trustees of the sandbeds, and have been responsible for development of the area as a major source of potable water since 1939. The sandbeds supply up to 30% of Newcastle's water needs during peak demand periods.

Mineral sands extraction has been carried out since 1972 by R.Z. Mines (Newcastle) Pty. Ltd. (RZM) within a series of mine leases administered by the Department of Minerals and Energy. Mining takes place under a series of controls with extensive monitoring, which enables the integrity of the groundwater resource to be maintained while allowing extraction of the valuable mineral resource.

The controls are designed to minimise the impact of mining on the aquifer, particularly in terms of water quality and aquifer recharge/yield characteristics.

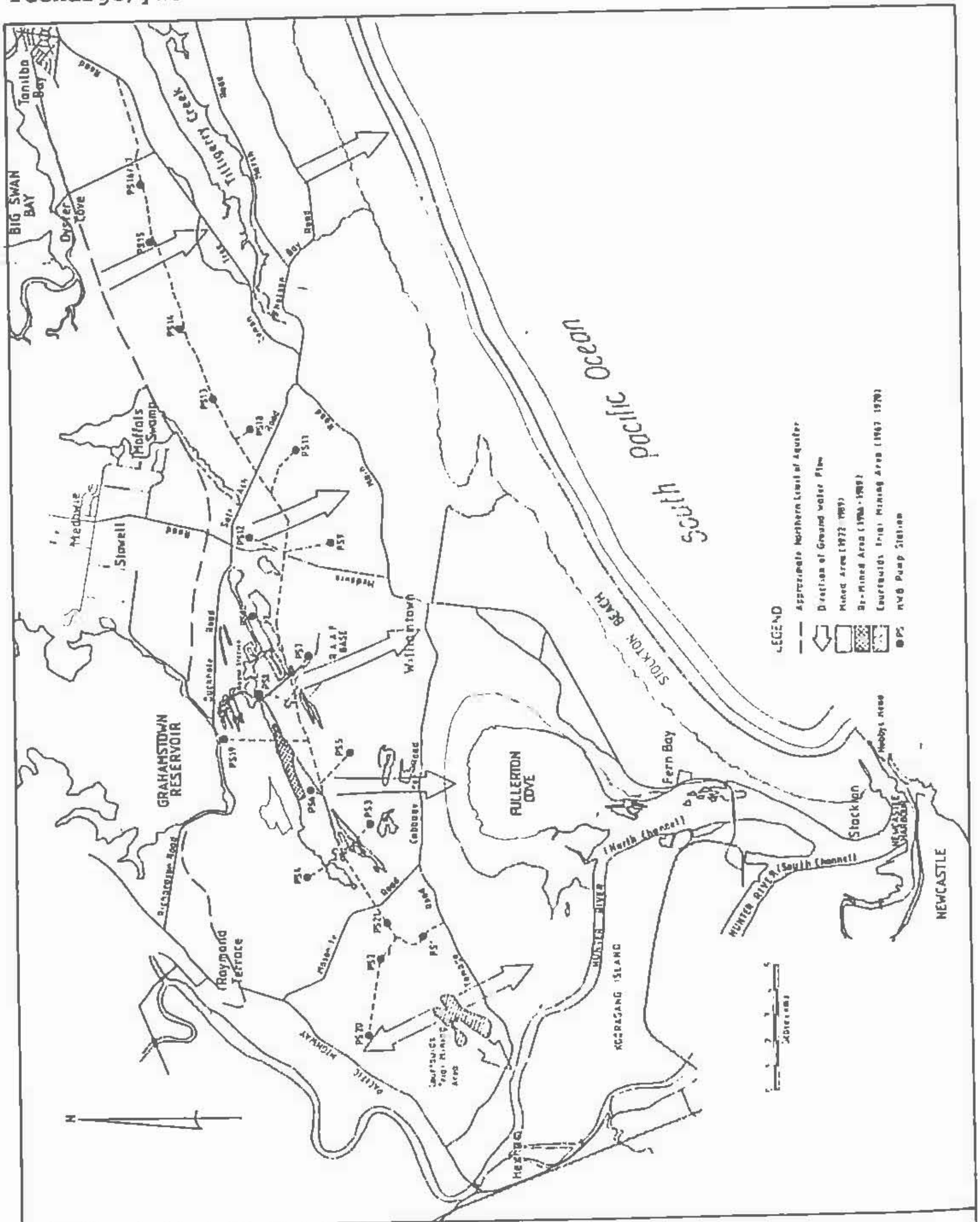

FIGURE 1 - LOCATION OF TOMAGO SANDBEDS

To date, approximately 600 ha of the Sandbeds has been mined, of which about 50 ha has been re-mined.

2. STRATIGRAPHY

The sandbeds may be described in summary as consisting of a medium grained quartzose sand deposit containing occasional clay and indurated sand layers.

From a study of several hundred soil samples (Ref. 1) taken throughout the sandbeds, it was found that a convenient division of the strata could be made based on colour as follows:-

- Upper light coloured sands (ULS)
- Dark coloured sand (DS), occasionally cemented or indurated
- Lower light coloured sand (LLS)
- Grey coloured sand (GS).

The ULS, DS and LLS are of similar particle size with an average D10 size ranging from 0.15mm to 0.16mm. Mining to date has been generally confined to these units. The lower GS strata has substantially more fines than the above with an average D10 size of 0.08mm.

The sandbeds are underlain by the Tomago Coal Measures, and varying thicknesses of clay deposited within the Tomago Basin prior to the deposition of sand, which contains the heavy minerals.

3. AQUIFER PARAMETERS

A number of studies have been carried out to assess the permeability and to a lesser extent the storage coefficient of the sandbeds. Available data is summarised in Tables 1 and 2.

It has been inferred (Ref. 6) from data similar to that in Table 1 that pre-mining horizontal permeability of the sandbeds is generally in the range of 1.5 to 2.5×10^{-4} m/sec. Vertical permeability in some areas of the sandbeds is likely to be significantly lower owing to the presence of clay and indurated sand layers impeding vertical flows.

The mining process alters the physical characteristics of the aquifer to the depth of mining. The main effects are on cementation and permeability. The natural ground is often indurated, sometimes so strongly cemented that pre-ripping by dozers is required to assist progress of the dredge. The mining process breaks down the cementation and stratification of the sandbeds, and the resulting tailings are relatively homogeneous. This, in conjunction with a degree of bulking, leads to a generally higher premeability within the tailings than unmined ground. The average increase in permeability has been measured to be in the order of 50% (Ref 6).

TABLE 1

PERMEABILITY ESTIMATES

Source	Test Method	No. of tests	Permeability ($\times 10^{-4}$) m/sec Pre mining	(PM) Post mining
Lloyd Ref 2	Pumping Tests	1	0.33	
Gerard & Herzog Ref 3 (Courtaulds area)	Pumping Tests Pumping Tests	3 2 PM	2.4 - 2.6	2.7 - 3.5
HWB Ref 4 (Pump Station 6)	Pump Test Pump Test	1 1	1.9 7.0	
SML Ref 1 (Courtaulds area)	Rising/Falling Head Rising Head	7 3 PM 9 8 PM	1.9 - 2.5 1.7	2.5 - 3.4 2.5
SML Ref 1 (Whole Catchment)	Rising/Falling Head	100	1.5	
SML Ref 1 (Based on particle size grading and Hazen's formula)	ULS, DS & LLS GS Hazen (weighed average	207 72 299	2.6 0.64 1.9	
	Tailings Tailings	20 20		4.6 1.2

TABLE 2

ESTIMATES OF STORAGE COEFFICIENT

Source	Storage Coefficient
SML Ref 1*	0.33
Gerard & Herzog Ref 3#	0.16 - 0.21 (0.26 - 0.33) after mining
Viswanathan Ref 5	0.1
ERCON Ref 8	0.2

* Based on laboratory studies

\# Distance - drawdown approach, other methods used by the authors reported before mining storage coefficients of up to 0.34.

The tailings profile is, however, not entirely homogeneous. The dredging separates out the fine soil particles (passing 0.075mm sieve), and without precautions, a layer of organic-rich soil fines (referred to as "slime") forms on the pond bottom. This material, which is basically a silty clay, has a much lower permeability than the natural sands or tailings - in the order of 6×10^{-9} m/s. For many years the slime was removed via a large settling tank and flocculent, then pumped to storage dams off the catchment. More recently, RZM has been permitted to deposit fines with the tailings in a beach fashion in order to disperse the fines throughout the profile, with excess slime being deposited in surface dams on mined ground. However, the beach mode of tailings deposition usually creates an uneven distribution of soil fines. The result is a concentration of soil fines near pond bottom. Hence, although most of the tailings profile is initially of higher permeability than pre-mining, the lower permeability layer near pond bottom controls vertical flow. The relationship between fines content and vertical permeability has been studied in the laboratory, and the results are shown in Fig 2. It was concluded that the fines content of the tailings in any discrete layer should not exceed 10% so as not to significantly retard aquifer recharge.

In regard to the storage coefficient, available data summarised in Table 2, it is considered most likely that values in the order of 0.1 to 0.2 most closely approximate the storage coefficient of the Tomago Sandbeds.

4. GROUNDWATER LEVELS AND FLOW DIRECTIONS

General groundwater levels within the sandbeds fluctuate with climatic conditions, however, the overall groundwater flow directions remain relatively constant. The groundwater level variation with time, taken from a representative monitoring point (SK 4226), is shown in Fig 3. Water level fluctuations in the order of 6m to 7m have been recorded over the monitoring period of this spearpoint (18 years), exaggerated during the drought periods of 1980 and 1983 by heavy pumping from nearby Pump Station 6. Natural water level fluctuations (assessed from other spearpoints) over the same period have been about 4m to 5m.

Groundwater gradients may be described as being generally flat - up to 0.3% regionally. Locally of course higher gradients are associated with the extraction of groundwater at the HWB Pump Stations. The direction of groundwater flow is shown on Fig 1, based on contours derived from monitoring spearpoints. It may be seen that flow direction is generally towards Fullerton Cove, Hunter River and Tilligerry Creek.

While definitive studies have not been carried out, tentative natural flow rates of about 2 m/year vertically and 6m to 40 m/year horizontally have been suggested (Ref 7).

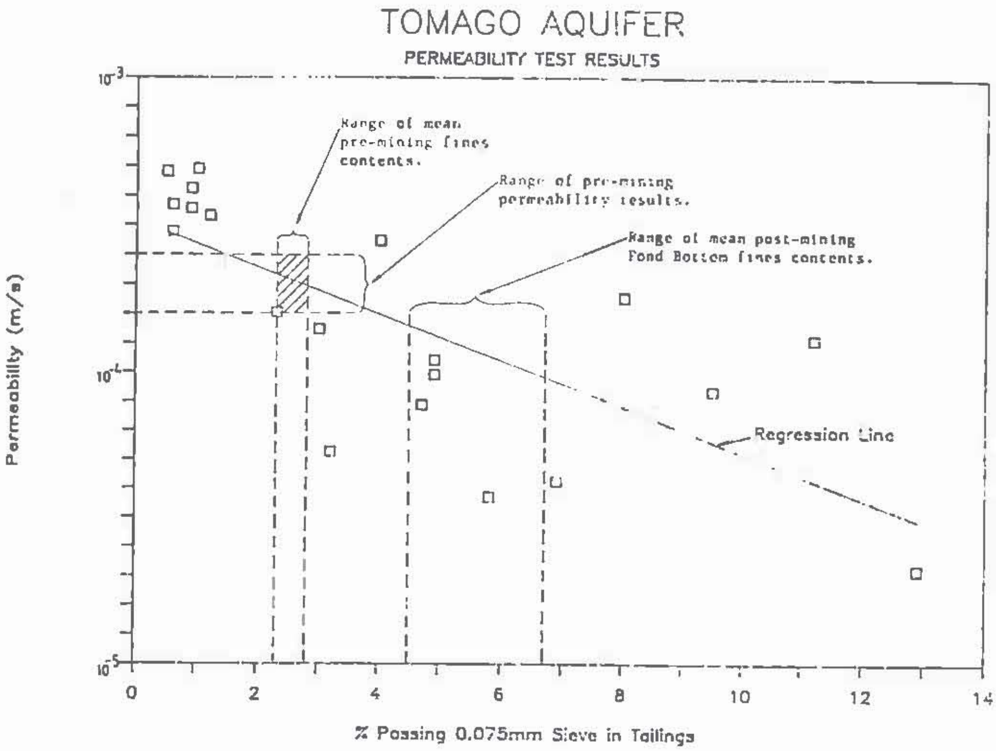
TOMAGO AQUIFER
PERMEABILITY TEST RESULTS
Range of mean pre-mining fines contents.
Range of pre-mining permeability results.
Range of mean post-mining Pond Bottom fines contents.
Regression Line
Permeability (m/s)
% Passing 0.075mm Sieve in Tailings

Fig. 2

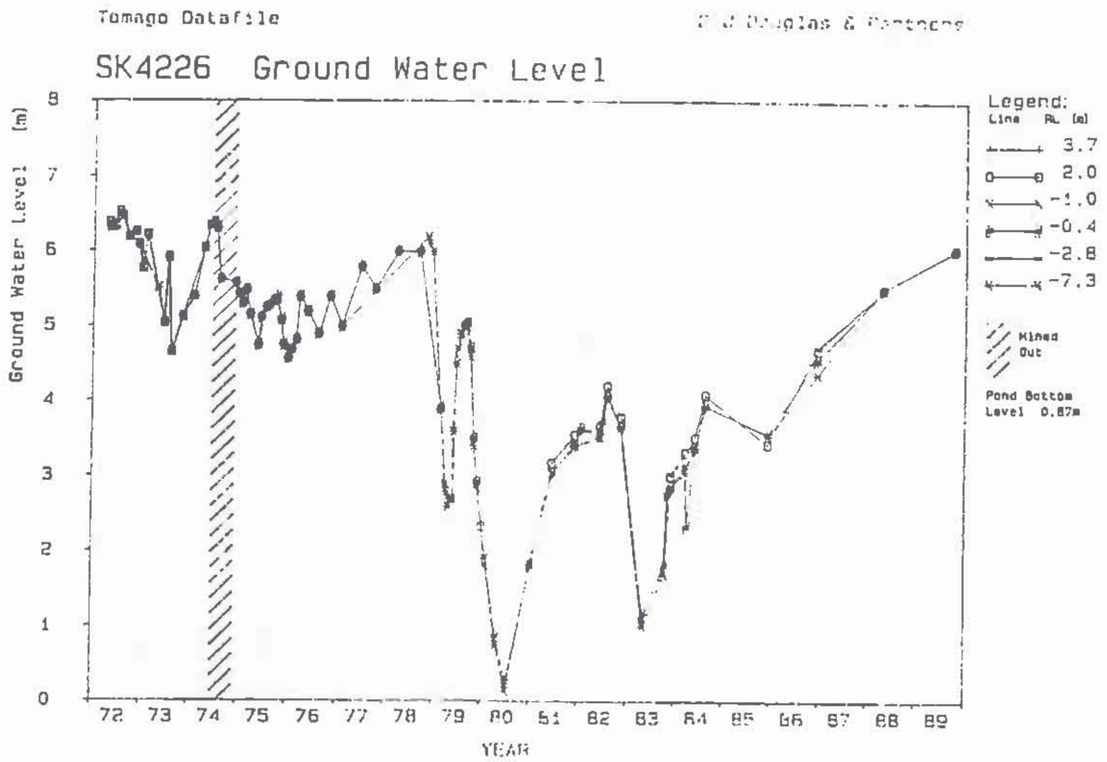
Tomago Datafile
SK4226 Ground Water Level
Ground Water Level (m)
Legend:
3.7
2.0
-1.0
-0.4
-2.8
-7.3
Mined Out
Pond Bottom Level 0.87m
YEAR

Fig. 3

5. SAFE AQUIFER YIELD/WATER BALANCE

Rainfall records at Pump Station No. 1 from 1942 to 1983 show a long term average yearly rainfall of 1134 mm. The combined outflow and evapotranspiration is indicated to be in the range 800 to 1000 mm per year (Ref 8).

With the exception of studies by Dr Viswanathan (Refs 5 & 9), little research appears to have been published on studies aimed at establishing a rigorous water balance model for the sandbeds or its safe yield.

A number of modelling exercises for the Tomago Sandbeds have been documented in unpublished reports to the HWB by Soil Mechanics Ltd. (SML) in 1967, 1971 and 1986.

The major uncertainty in the modelling undertaken is the absence of realistic treatment of aquifer outflow or evapotranspiration. Almost traditionally these variables have been treated as black box unknowns or by lumping with the other losses leading to a high degree of uncertainty in model predictions.

In regard to aquifer yield, Ref 9 considered a range of yields up to 120 Ml/day and concluded that the maximum yield over a two year period with rainfall of 600mm p.a. would be 92 Ml/day.

6. WATER QUALITY

The groundwater quality within the mined zone, and surrounding control points, is regularly sampled from an array of more than 240 monitoring locations. Each monitoring location has two or more spearpoints at different depths within the aquifer. The test results are stored, collated and analysed by Douglas & Partners using a purpose-written database system.

Monitoring of up to 13 chemical constituents has shown that the main parameter of concern is soluble iron, which must leave the treatment works at a maximum of 0.3 mg/l. Current HWB treatment plant and techniques require that the influent iron concentration should not exceed 5 mg/l. This is achieved by mixing "good" and "bad" quality waters from the various pumping stations.

The natural levels of soluble iron vary widely across the sandbeds and the response in iron levels to mining also varies widely between individual monitoring points. A typical response to both first mining and re-mining at a single monitoring point is shown in Fig 4 (SK 6780). The effect is best understood, however, by observing overall trends. Within 1 to 2 years after mining there is an increase in average soluble iron levels at most monitored sites from a general background level of 1 to 5 mg/l to about 10 mg/l (Fig 5). The general trend is for the higher iron concentration to persist for at least 8 to 10 years. There is an apparent decrease in average soluble iron after 10 years, however there is insufficient long-term data to be certain of this.

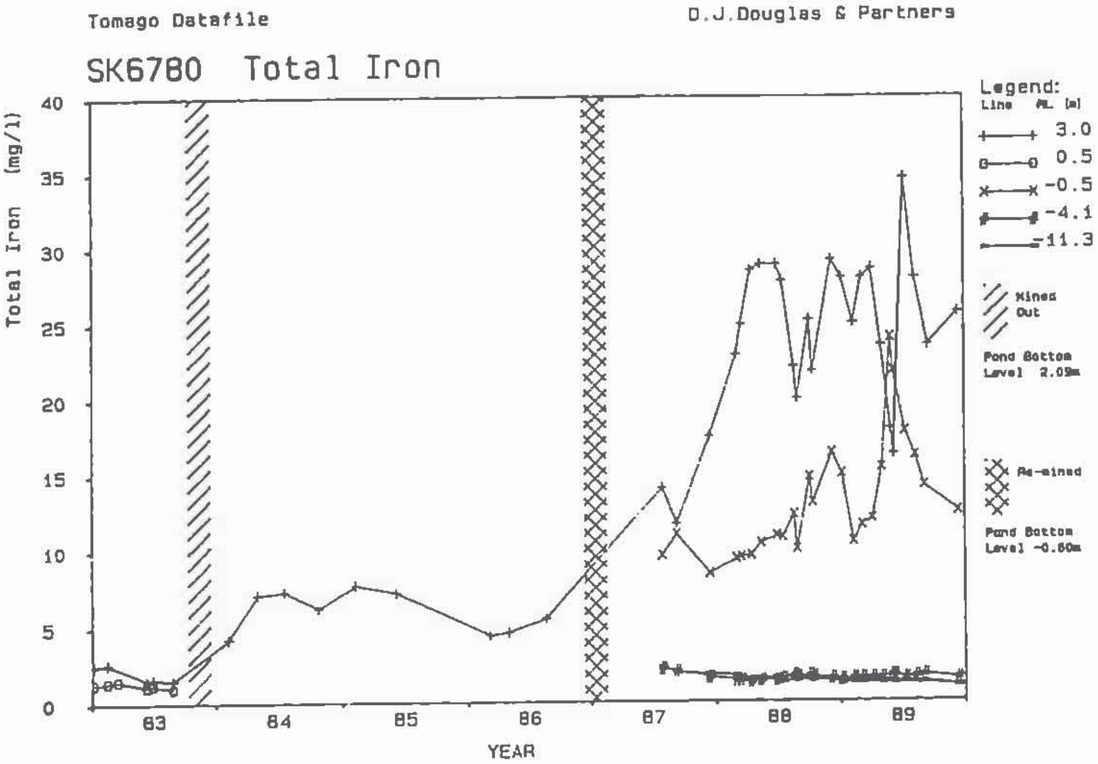

Fig 4

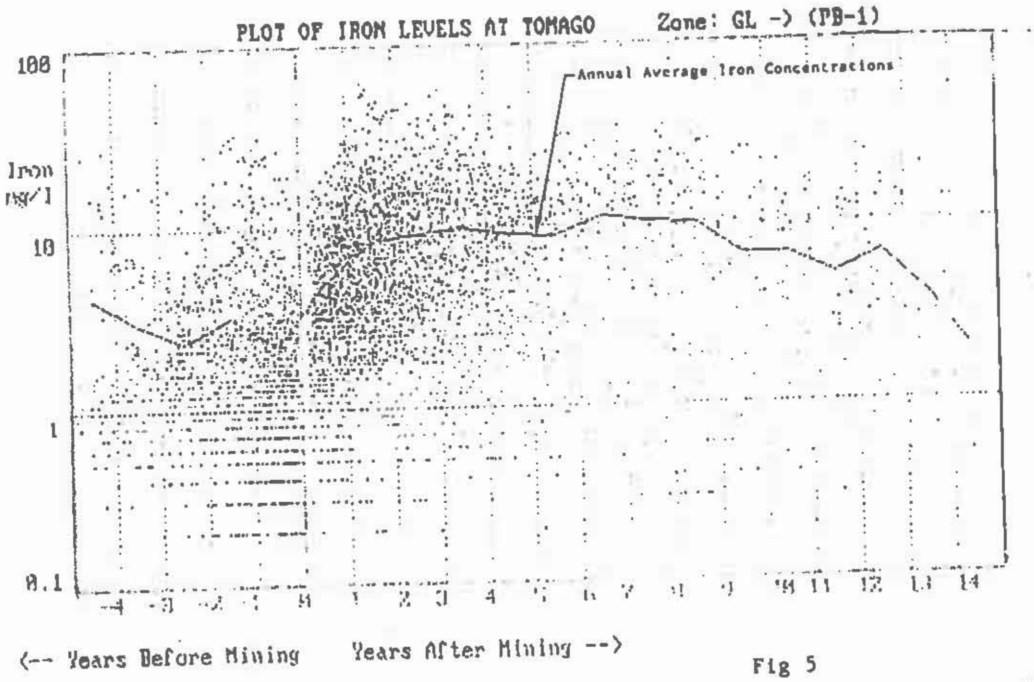

Fig 5

TOMAGO SANDBEDS AQUIFER

In the re-mining area, the general background level of soluble iron is 3 to 8 mg/l rising to 7 to 15 mg/l after first mining. Following re-mining soluble iron levels have risen generally to 20 to 60 mg/l and there is no indication at this stage whether these values have peaked.

Various mechanisms have been postulated to explain the rises in iron levels following mining and include factors such as soil chemistry, microbiology, leaching of organic acids, and changes in water level (both climatic and pumping induced). Due to the complexity and variability of these reactions, none have been fully explained and research is continuing at various organisations.

It is clear that the range of chemical responses observed at Tomago cannot be explained by one single mechanism and at any given site a combination of mechanisms is in play. Regardless of the cause, the result is potentially greater treatment costs to the HWB, and loss of flexibility in mixing low and high quality waters. Annual water extraction fees paid by RZM to HWB are designed to cover the additional costs.

7. ACKNOWLEDGEMENTS

The authors wish to thank the Hunter Water Board for their permission to publish this paper.

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